United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-132

July 1982

Management Consequences of Alternative Harvesting and Residue Treatment Practices— Lodgepole Pine

Robert E. Benson

Approved for publication by Intermountain Station
March 1982

PREFACE

This study was undertaken as a cooperative effort among Intermountain Station, Region 4, and Champion International on the Bridger-Teton National Forest in 1971. At the time, land managers were primarily concerned about management of logging residues, particularly in reducing visual impacts and costs of treatment.

The main goal of the study was to evaluate equipment and methods for chipping residues on site. Research efforts in monitoring the longer term consequences of the study were of necessity designed to fit the harvest activities. The harvesting operations, costs, and initial responses on the site have been previously published in various reports.

In the decade since study was begun, there have been marked changes in wood utilization. Land management and planning requirements have greatly expanded the need for information regarding long-term impacts of alternative harvesting practices. Limitations in the initial scope and design of the study were such that some important questions cannot be answered, except as speculations. Nevertheless, our intent is both to present research data and to integrate findings into a useful reference for managers.

This report stems from the need to interrelate individual findings in a manner that illustrates the consequences of management decisions. The manager may not have the time or the skills needed to correlate many separate results.

The goal is to translate the physical and biological responses of the harvest activities into interpretations readily adapted to the manager's needs. Where data from this study are lacking or inconclusive, perhaps the methodology and references will provide some assistance. It should be pointed out, however, that while the intent is to integrate and reference research findings, this report is not a "cookbook" or substitute for the manager's on-the-ground knowledge and judgment.

This report summarizes and integrates the findings of a team of Intermountain Station scientists and cooperators. The principal Forest Service participants in the study are listed below, and sections prepared by individuals are identified in the text. Other sections were prepared by the study coordinator.

Robert E. Benson, Forestry Sciences Laboratory, Missoula (Study Coordinator)
Joseph V. Basile, Forestry Sciences Laboratory, Bozeman
James K. Brown, Northern Forest Fire Laboratory, Missoula
Dennis M. Cole, Forestry Sciences Laboratory, Bozeman
Norbert V. DeByle, Forestry Sciences Laboratory, Logan
Rulon B. Gardner, Forestry Sciences Laboratory, Bozeman (retired)
George E. Gruell, Northern Forest Fire Laboratory, Missoula
Alan E. Harvey, Forestry Sciences Laboratory, Moscow
Roger D. Hungerford, Forestry Sciences Laboratory, Missoula
James E. Lotan, Northern Forest Fire Laboratory, Missoula
Paul E. Packer, Forestry Sciences Laboratory, Logan (retired)
Wyman C. Schmidt, Forestry Sciences Laboratory, Bozeman
Bryan D. Williams, Forestry Sciences Laboratory, Logan

In addition to the study team members who authored individual sections, several team members and cooperators made substantial contributions of fieldwork, data, or analyses, as described below:

George E. Hart, Robert W. Hennes, John J. Skujins, and **Alvin R. Southard.**—These cooperators at Utah State University, Logan, contributed fieldwork, analyses, and reports that are incorporated into the sections on soil properties and nutrients, and soil microorganisms.

George E. Gruell, Northern Forest Fire Laboratory, while stationed on the Bridger-Teton, conducted field assessments and made summaries that are incorporated in sections on wildlife responses, wildlife values, and grazing values.

Reed Stalder, while stationed in the Regional Office, Ogden, made field assessments and summaries that are incorporated into the section on esthetic and recreational values.

Paul E. Packer and Bryan D. Williams conducted fieldwork and contributed reports that are incorporated into the soil and water section.

Resources Evaluation Research Work Unit, Intermountain Station, Ogden, provided pre- and postharvest inventory data on timber, residues, and ground cover.

The Supervisor's Office and the Gros Ventre District of the Bridger-Teton provided continuing assistance in locating the field site, arranging work schedules, and supporting the research team in conducting research and field workshops.

A special acknowledgment goes to Dr. DeByle who provided valuable comments throughout all phases of preparing this report.

RESEARCH SUMMARY

A harvesting study in mature lodgepole pine compared four harvesting and logging residue treatments. Residues were piled and burned, broadcast burned, chipped and spread back on the ground, or removed from the site. On all four harvesting treatments regeneration by planted seedlings, direct seeding, and natural regeneration was compared.

The harvesting was done in 1971, and since that time a series of research studies has measured the effects of the treatment on soils, soil microbiology, nutrients, water, microclimate, tree survival and growth, vegetative development, wildlife habitat, and esthetics. A comparison of logging costs and returns, and projected future stand conditions are included in an economic analysis.

The initial net dollar returns were slightly higher with the residue-burned treatments than when residues were removed or chipped. Utilization standards and wood values have changed considerably in the past decade.

The effects of the different treatments on the site varied. In general, survival and growth of regeneration was best on the residue-burned treatments. The chip-spread treatment greatly inhibited regrowth of both trees and other vegetation. There was no clear picture of why these differences occurred, but on the residue-removed and chip-spread treatments presence of phenols in the water, creation of unfavorable microsite conditions, and soil compaction may have contributed. Based on initial mortality and growth, future stands will probably have notable differences in stocking volume.

The initial visual impact of the residue-removed treatment was less severe than the residue-burned treatments. But the burned treatments provided better habitat for most wildlife species.

It is evident that different harvest treatments result in a complex interaction among the different impacts. An estimate of how different use opportunities are affected, and a method for comparing tradeoffs are presented.

THE AUTHOR

ROBERT E. BENSON is a research forester assigned to the Systems of Timber Utilization for Environmental Management Program, and has been with the Intermountain Station in Ogden and Missoula. His research includes studies in forest economics, wood products marketing, forest inventories, and resource analyses.

CONTENTS

	Page
Introduction	1
The Study Site	1
Study Design and Treatments	2
Harvest and Postharvest Activities	4
Logging and Utilization	4
Fuels and Burning	4
Site Preparation and Regeneration	7
Primary Responses	7
Biomass and Cover	7
Microenvironmental Effects	8
Soil Properties and Nutrients	9
Surface Organic Layer	9
Mineral Soil	10
Soil Solutions	12
Surface Hydrology and Soil Stability	13
Soil Microorganisms	14
Soil Microbial Properties	15
Nitrogen Mineralization	15
Nitrogen Fixation	15
Ectomycorrhizae	16
Long-term Implications	17
Second Responses	18
Regeneration and Growth of Conifers	18
Planting	18
Spot Seeding	20
Natural Regeneration	22
Factors Affecting Regeneration	22
Projections of Timber Stand Development	23
Regrowth of Understory Vegetation	26
Wildlife	26
Effects on Wildlife Habitat	26
Observations of Wildlife	27
Effects On Use Opportunities	28
Wildlife Values	28
Grazing Values	30
Esthetic and Recreational Values	31
Public Viewer Evaluation	31
Manager Evaluation	32
Soil and Water	32
Timber	33
Costs and Returns	34
Management Implications	35
Comparing Alternatives Using Net Dollar Returns and Nondollar Indexes	35
Tradeoffs Among Alternatives	35
Summary of Treatments	40
Pile/Burn	40
Broadcast Burn	40
Residue Removed	41
Chip-Spread	41
An Update and Overview	41
Publications Cited	41
Appendix	44

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-132

July 1982

Management Consequences of Alternative Harvesting and Residue Treatment Practices— Lodgepole Pine

INTRODUCTION

In recent years there has been growing concern over timber harvesting practices and the disposal of the resulting logging residues. Although various methods of harvesting and handling residues have been considered, economic feasibility of the alternatives and their effects on the forest resource and future management have remained in question.

In 1971 the Intermountain Forest and Range Experiment Station, the Intermountain Region, and Champion International Inc. undertook a cooperative study to evaluate several systems of harvesting mature lodgepole pine (*Pinus contorta* Dougl.) and to compare postharvest treatments. Studies included effects of different treatments on soil and water, tree regeneration and vegetation, esthetics, harvesting costs, and management activities. Principal design and analysis of the study was by the Intermountain Forest and Range Experiment Station, with the Teton National Forest, the Intermountain Region, and the Forest Products Laboratory cooperating. (In 1973 the Teton National Forest was combined into the Bridger-Teton National Forest.)

Since 1971, utilization has changed significantly. Rising demand for wood products and a declining timber base have increased the feasibility of using more of the dead material. A substantial market for house logs using dead trees has developed throughout the lodgepole region, and use is increasing for stovewood, pulp chips, and other products. Many of the problems of processing dead timber for lumber have been overcome.

The Study Site

The study site is located near the Union Pass area southwest of Dubois, Wyo., on the Bridger-Teton National Forest (fig. 1). This area is a high, gently rolling plateau about 9,000 to 9,800 ft (2 700 to 3 000 m) elevation. Slopes range from 5 to 25 percent.

The area consists of a mixture of very large open sagebrush and lupine meadows, wet meadows, and extensive timber stands interspersed with small meadows and potholes. There are sizable populations of moose, antelope, elk, and some deer. Cattle are grazed throughout the area in the summer, and there is considerable fishing, hunting, and other recreation in the area.

Soils on the study site developed in glacial till, and classify as Mollic Cryobaralfs and Mollic Cryochrepts.[1] The surface organic horizon is 0.8 to 1.2 in (2 to 3 cm) thick. The underlying mineral soil is typically loam, progressing downward to sandy and gravelly loam.

Lodgepole pine (*Pinus contorta* Dougl.) comprises 75 to 90 percent of the timber volume. Virtually none of the lodgepole pine is serotinous. Engelmann spruce (*Picea engelmannii* Parry), subalpine fir (*Abies lasiocarpa* [Hook] Nutt.), and limber pine (*Pinus flexilis* James) make up the remainder. The principal habitat type is *Abies lasiocarpa/Vaccinium scoparium* (Steele and others 1979).

---

[1]Reported by DeByle (1980), based on his personal communication with A. R. Southard, Utah State University, Logan.

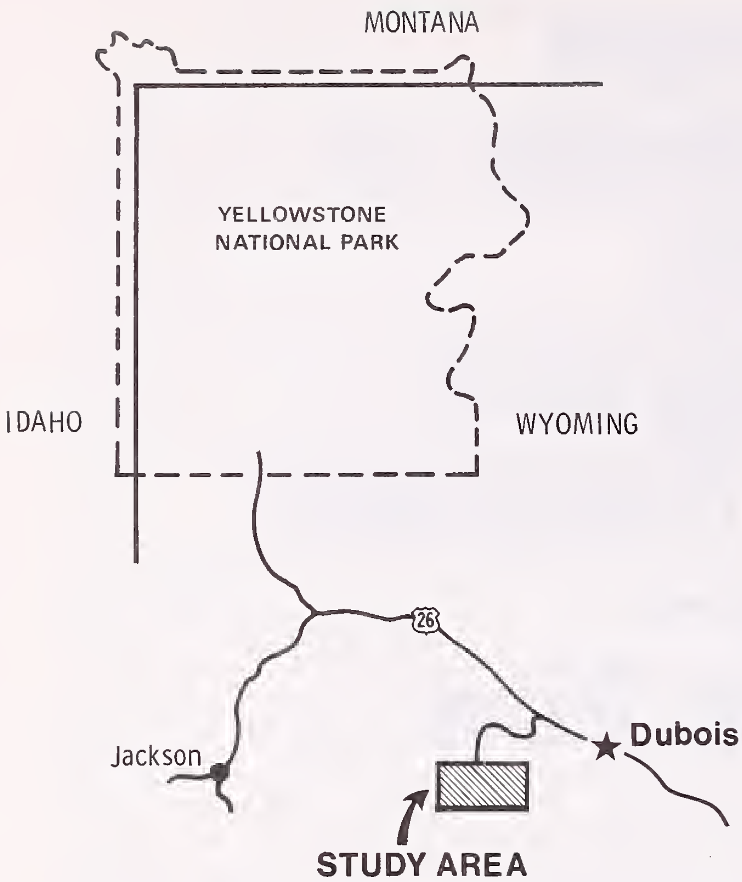


Figure 1.—Location of study area, Bridger-Teton National Forest.

The study site is typical of high-elevation, mature lodgepole pine stands: about 300 live trees per acre (740/ha) and 100 dead trees (250/ha), pole size (5 in [12.7 cm] d.b.h.) or larger. The principal stand is even-aged, about 160 years old. Most of the understory conifers are limber pine seedlings.

The total volume of standing trees ranges from about 7,000 to 9,600 ft³/acre (2 800 to 3 900 m³/ha). About 75 percent of this is sound sawtimber trees that is net volume after deducting for defect; 10 percent is the top portions of sound trees; and the remaining 15 percent is small trees, cull trees, and cull portions of saw logs. Detailed timber data on the study units are presented in the appendix.

Near the study site, logging was begun in the 1950's and has continued to the present. Because stands are old and have no manageable understory, the usual harvest method is to clearcut in units of 15 to 30 acres (6 to 12 ha), although some of the first cutting units were larger. Residues were tractor-piled and burned, and sites were usually regenerated by planting. Figure 2 shows a typical cover pattern for the area: meadows 25 percent, uncut forest 60 percent, and cutover 15 percent.

Understory vegetation is relatively sparse on the site due to a short growing season, limited moisture during the growing season, and a dense, uniform tree crown overstory. The understory averages about 250 to 300 lb/acre (280 to 335 kg/ha), with the major components as follows:

Component	Percent
Shrubs	34
Seedlings	10
Forbs	39
Moss	12
Grass	5
	100

The study area did not show evidence of sizable fires during the life of the stand, but fire is apparently a common part of the forest cycle. The fire-free interval is no doubt relatively long, perhaps several hundred years.

Study Design and Treatments

The study site consisted of four 20-acre (8-ha) units harvested by clearcutting. Two units were logged with conventional practices for the area at that time; green saw logs to a 6-in (15-cm) top were removed, and the remaining material was left for burning on the site ("green" includes recently dead trees that are sound). The other two units had residues removed. In addition to taking out the merchantable saw logs, virtually all other material was yarded and chipped. On these units a feller-buncher and rubber-tired grapple skidder were used in combination with a mobile chipper (fig. 3). The equipment and the utilization methods were new to the area. The logging and postharvest treatments are as follows (refer to fig. 4).

Units 1 and 4—Residues Removed

—Logging (summer 1971): feller-buncher and grapple skidder.

—Utilization: all pieces down to a 3-in diameter by 8 ft long (7.6 cm by 2.4 m) were skidded to landing, where green saw logs were bucked out.

—Residue treatment: all residues were chipped and piled on the site.

—Half of each unit was left as is after the removal of residues. On the other half of each unit, chips were spread back on the ground during the fall of 1972 and spring 1973 in approximately the same amount as residues were removed ("chip-spread"). This resulted in a bed of chips about 4 to 6 in (10 to 15 cm) deep.

Units 2 and 3—Conventional Utilization

—Logging: trees felled by chain saws, saw logs bucked out, and logs skidded to landing using rubber-tired tractors with chokers.

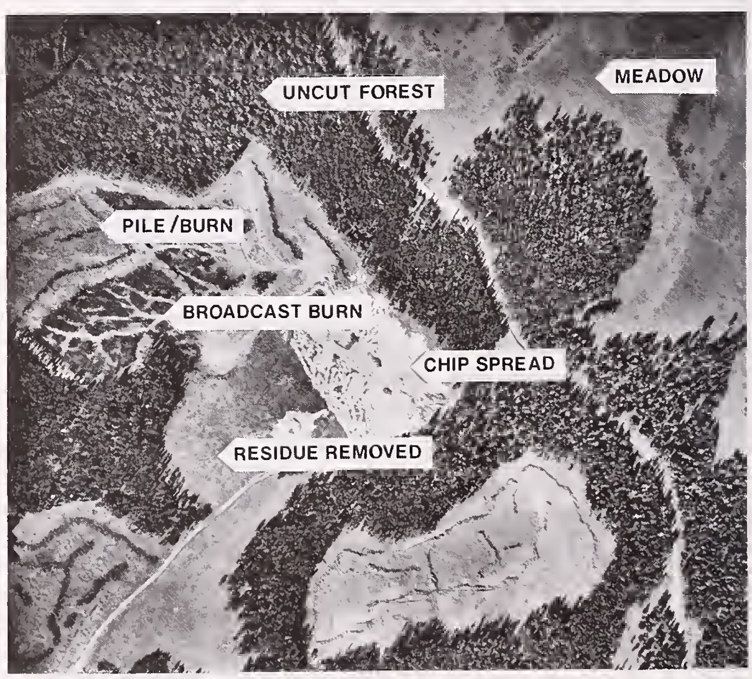


Figure 2.—Typical cover pattern for the study site.

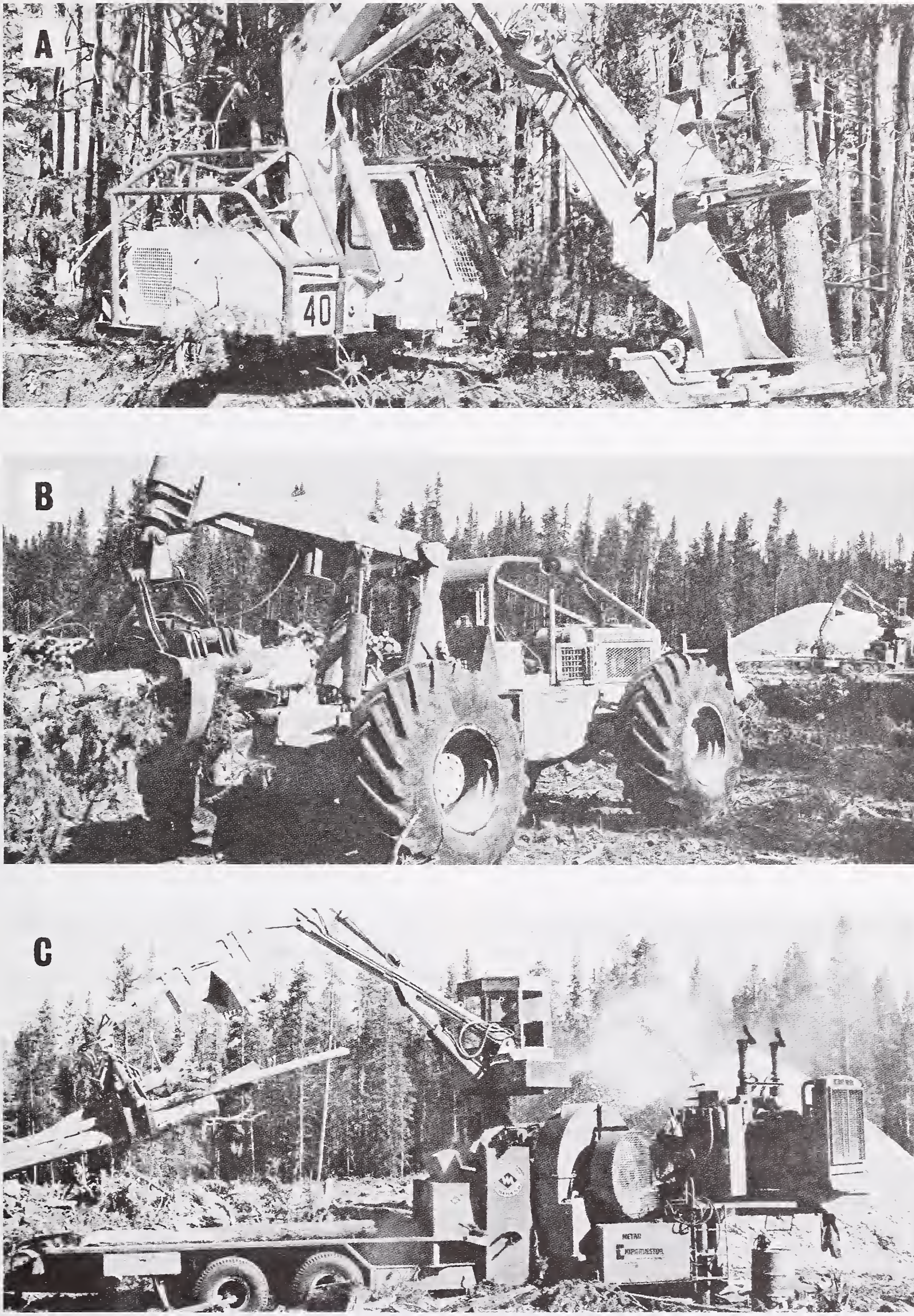


Figure 3.—Equipment used in residues-removed logging: (A) feller-buncher; (B) grapple skidder; (C) chipper.

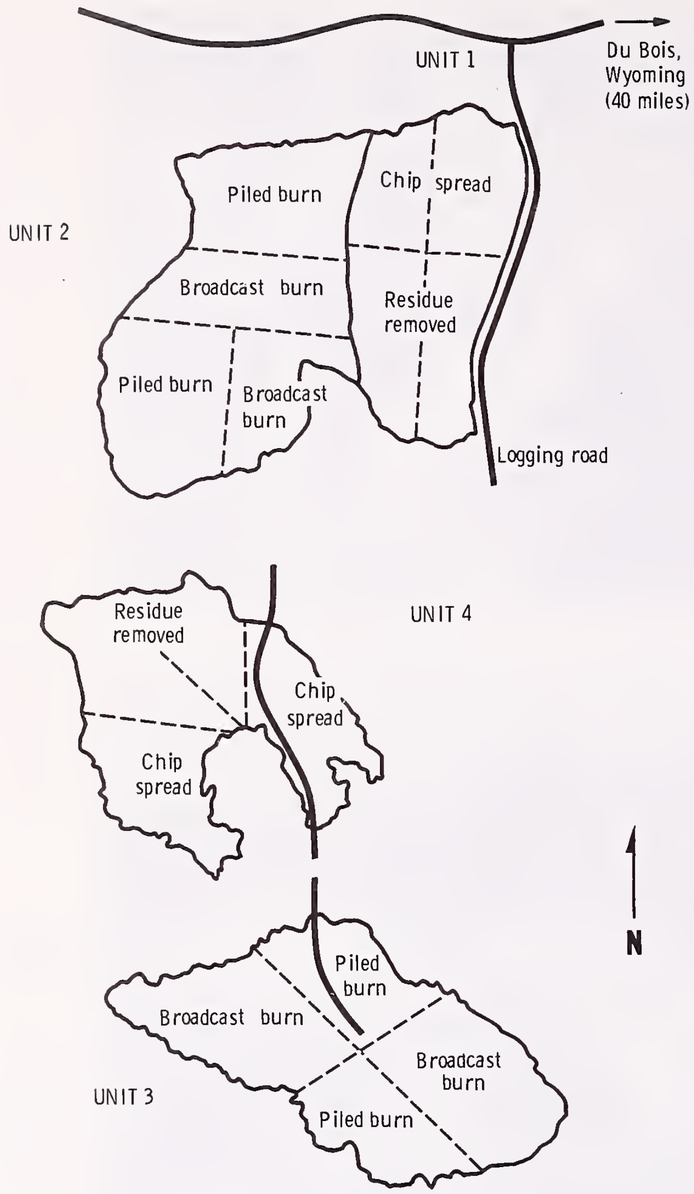


Figure 4.—Cutting units and residue treatments.

—Utilization: "conventional" utilization for the area—green saw logs to 6-in (15-cm) top diameter.

—Residue treatment: slash on half of each unit was left in place and broadcast burned in spring 1973. On the other half, slash was piled by crawler tractor with blade, and the piles burned in the fall of 1972.

Although there was no market for chips in the area in 1971, residues were chipped to estimate the costs of recovering fiber and to evaluate the impacts of removing residue from the site. Some chips were used for experimental products and some were used as ground cover at a local rodeo arena and campground. The chip-spreading was done to evaluate such a treatment as an alternative to burning slash.

To study tree regeneration, the quadrants on all units were divided into thirds. In June 1973 one-third of each quadrant was planted with 2-0 lodgepole pine, one-third was spot seeded to lodgepole pine, and the remaining third was left for natural regeneration. Planting and spot seeding were done in small, hand-scalped areas, each about 18 in (45 cm) square.

HARVEST AND POSTHARVEST ACTIVITIES

This section describes harvest methods, postharvest site treatment, and regeneration activities carried out during 1971–73 on the site. Most of these have been discussed in detail in earlier published reports. These reports are briefly summarized in this section and updated, where appropriate, with new information developed since the study was initiated.

Logging and Utilization

Logging in the conventional units described above was typical for the area at the time of study (1971). Green saw logs were the principal product, and a very limited amount of dead or small material was removed as saw logs. Saw logs were trucked to the Dubois, Wyo., sawmill.

Production time for logging equipment was recorded daily and volumes of saw log and chipped residues were measured. These data were combined with average equipment costs to derive logging productivity and costs. The 1971 costs of logging averaged from \$31 to \$35 per M bd.ft. for saw logs, and \$19 to \$20 per bone dry unit (BDU) of chips. These costs include all equipment, labor, and supervisory costs at the field level, and also hauling costs to Dubois, 40 miles. Details of the logging study were reported by Gardner and Hartsog (1973).

To make these data more generally applicable, hauling costs were deducted, and data were adjusted for differences in stand volumes on the different units, as described in the appendix. The 1971 and updated 1980 costs were as follows:

	1971	1980
Saw logs, stump to truck		
Conventional units, \$/M bd.ft.	20.26	36.27
Residue-removed units, \$/M bd.ft.	20.64	36.95
Chips, stump to truck, \$/BDU (\$/ft³)	13.09 (0.137)	23.43 (0.245)

On conventional logging units slash disposal was as follows: (1) piled with a crawler tractor, then burned (conventional method in the area); (2) left for broadcast burning, with no treatment except a bulldozed fireline. The costs of these treatments were:

	1971 dollars	1980 dollars
Pile/burn, piling, \$/acre	35.71	63.92
Broadcast burn, fireline, \$/acre	4.86	8.70

Fuels and Burning

James K. Brown and James E. Lotan

To assess the effects of the two utilization standards on fuel characteristics, fuels were inventoried before and after logging. Sampling was done using a grid. At each sample point, fuel loading (weight per unit area) by size class, fuel depth, duff depth, and percentage of ground cover were measured. The branch wood size classes were 0 to 0.20 in (0 to 0.5 cm), 0.21 to 0.60 in (0.5 to 1.5 cm), 0.61 to 3.0 in (1.5 to 7.6 cm), and larger than 3.0 in (7.6 cm). The first three classes correspond

Table 1.—Ground fuels before and after logging, by component weight and percent cover

Fuel item	Residue-removed			Conventional		
	Before	After	Change	Before	After	Change
	Tons/acre (metric tons/ha)					
Loading						
Needles	0	0.40	0.40	0	1.05	1.05
Branch wood, inch (cm)						
0.0-0.2 (0.0-0.5)	0.14	.10	−.04	0.20	.15	−.05
0.2-0.6 (0.5-1.5)	.82	1.32	.50	.96	1.92	.96
0.6-3.0 (1.5-7.6)	3.38	8.64	5.26	4.22	9.70	5.48
Total	4.34 (9.7)	10.46 (23.4)	6.12 (13.7)	5.38 (12.1)	12.82 28.7)	7.44 (16.7)
Over 3.0 (7.6)	27.0 (60.5)	9.0 (20.2)	−18.0 (−40.3)	16.5 (37.0)	44.0 (98.6)	27.5 (61.6)
	Percent					
Ground cover						
Mineral soil	2	42	+40	1	29	+28
Forest floor litter	48	26	−22	51	40	−9
Wood	21	31	+10	19	29	+10
Grass	22	0	−22	13	1	−12
Brush	2	0	−2	16	1	−17
	Inches (cm)					
Fuel depth	10.8 (27.4)	3.0 (7.6)	−7.8 (−19.8)	13.7 (34.8)	7.4 (18.8)	−6.2 (−15.7)
Duff depth	.92 (2.3)	[1]		.92 (2.3)	[1]	

[1]Not measured.

to the 1-, 10-, and 100-hour moisture timelag classes used in the National Fire-Danger Rating System. Bulk density of the duff was determined from 10 samples of 1 ft^2 (929 cm^2) systematically taken in each stand.

Fuel loading for downed dead branch wood was determined using the planar intersect technique (Brown 1974). For material less than 3 in (7.6 cm) in diameter, a 5-ft (1.5-m) line transect was located at each grid point. The numbers of branch wood particles intersecting the vertical plane projected by the 5-ft (1.5-m) line were tallied for the first three size classes.

The weight of fuels and percentage of ground covered by fuels before and after harvesting are summarized in table 1. These measurements were taken prior to slash piling. After piling, the windrows covered approximately 18 percent of the surface of the pile/burn units, as measured on aerial photographs.

The main differences in the two harvesting treatments were in the amount of material larger than 3 in (7.6 cm) and total fuel depth after logging. On the residue-removed units, weight of material larger than 3 in (7.6 cm) was reduced to one-third of the prelogging amount. On the conventional units, fuel weight tripled. Although fuels larger than 3 in (7.6 cm) contribute little to the spreading flame front, they do contribute measurably to total fire intensity. Larger fuels also contributed to fire spread by compressing smaller sized fuels and thus increasing their flammability.

Fuel depth was reduced by both harvesting methods, primarily by removing grouse whortleberry (*Vaccinium scoparium*). Change in fuel depth, however, is not as important to burning as the depth and packing ratio of fuel after logging. (The packing ratio is the ratio of fuel volume to the volume of the fuel bed.) The packing ratio for material less than 3 in (7.6 cm) averaged 0.062 on the residue-removed units and 0.030 on the conventional units. (The optimum packing ratio for combustion for this type fuel using Rothermel's model [1972] of fire spread was 0.009.) Thus, the packing ratio on the residue-removed units restricts combustion to a greater degree than on the conventional units.

Conventional utilization produced only slightly more material less than 3 in (7.6 cm) in diameter than did residue removal. On the conventionally logged units, however, a substantially greater percentage of residue was highly flammable needles than on the residue-removed units. After logging, material 0 to 0.2 in (0 to 0.5 cm) in diameter had decreased on both conventional and residue-removed units—probably because small materials had been crushed and churned into the forest floor.

Disruption of fuel continuity and exposure of mineral soil were greater on the residue-removed units than on the conventional units.

Duff, which averaged almost 1-in (2.5-cm) deep on all units, had an average bulk density of 8.7 ± 1.9 lb/ft^3 (140 ± 30 kg/m^3). Logging did not reduce the amount of duff, but did change its distribution.

Analysis and prescription.—Rate of fire spread and fireline intensity for the propagating flame front of a fire were estimated using the inventoried fuel data as inputs for the mathematical model of fire spread (Rothermel 1972). The model predicted that rate of spread after logging would be about 3 to 4.5 times greater

on the conventional blocks (fig. 5) than on the residue-removed blocks. Fireline intensity (heat from a 1-ft-wide cross section through the propagating flame front) was predicted to be about six times greater on the conventional blocks for any windspeed and fuel moisture for the first years (fig. 6).

Fireline intensity is probably the most useful characteristic of fire behavior for evaluating slash fuel hazard. At fireline intensities of 500 to 700 Btu's/ft, direct attack becomes ineffective and spotting begins to be a problem (Puckett and others 1977). At 1,000 Btu's/ft, crowning and serious spotting can be expected. Considering 500 to 700 Btu's/ft to represent an unacceptable hazard, figure 6 shows that for 1 to 2 years after cutting, conventional logging creates unacceptable hazards (Puckett and others 1979). After 3 to 5 years, hazard in conventional units falls to an acceptable level due to loss of needles and settling of slash. Figure 6 also shows a low hazard in the residue-removed units, even in the first years.

After the fuel assessment, a burning prescription was prepared. The primary objective of the burn was to reduce fuel hazard. Burning was to be carried out with a fire buildup index between 60 and 115, with an upper duff moisture content of 15 to 50 percent, and with a windspeed of less than 10 miles per hour.

Burning.—The plan was to burn the units in the fall of 1972. Unfortunately, as is common in that area, frequent storms during the late summer and fall prevented burning that year. In June of 1973, fuel conditions were reasonably dry and the decision was made to proceed with the burning. Spring or early summer burning is not normally done in the area, but the regeneration phase of the study would have been confounded by any further delay.

Departures from the prescription included burning in June after logging slash had overwintered. Fuel moistures were considerably higher than those prescribed because snowmelt had occurred only 2-3 weeks prior to the burn. This higher fuel moisture was offset to some extent by constant winds of more than 15 miles per hour. Further, needles in the slash had fallen to the ground and were compacted by winter snows. On the broadcast-burn units, prescriptions called for a fireline to be constructed with no jackpiling in the unit, but there were, in fact, windrows of slash on some edges of the uncut stand. Windspeeds exceeded those in the prescription, but not sufficiently to make the burn unsafe. Some scorching occurred, but this was due to excessively high windrowing of material pushed from the firelines on the perimeter of the units.

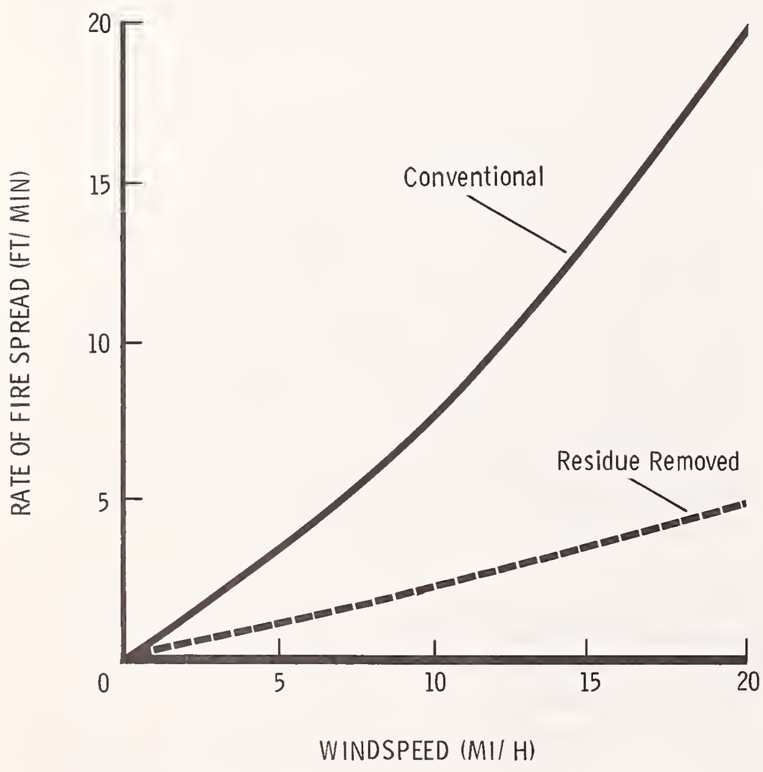


Figure 5.—Predicted rate of fire spread for logging residues, following conventional and residue-removed treatments.

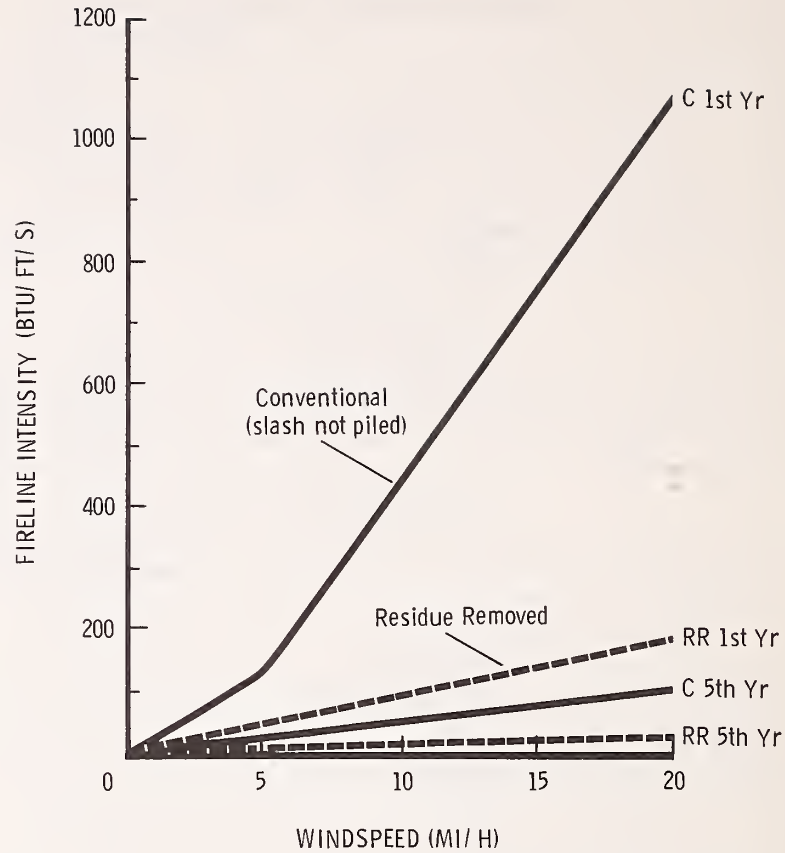


Figure 6.—Predicted fireline intensity by harvest method.

The burning was conducted on a June evening between 1900 and 2200 hours. Ignition followed a pattern from the center of the edges of the units; a column was created, but the strong, steady breeze kept it tipped over on a 45-degree angle for most of the burning. Windrows burned hot and caused some scorching of the uncut timber. In the broadcast-burn sections, burning occurred readily when continuous fuels were present.

Following the burning, the volume of material larger than 3 in (7.6 cm) was estimated. On the broadcast burns, the planar intercept method was used. On the pile/burn units, 50-ft segments of piles were randomly selected and the size of all pieces was recorded for computing an estimate of the material remaining. Volume of woody material on the pile/burn units averaged about 42 percent of the preburn volume, and on the broadcast burns averaged about 66 percent of the preburn volume. The costs of burning were as follows:

	1971 dollars	**1980 dollars**
Broadcast, $/acre	13.81	24.72
Pile/burn, $/acre	7.70	13.78

Site Preparation and Regeneration

James E. Lotan

Clearcutting is the most practical silvicultural method for regenerating lodgepole pine (Tackle 1954; Lotan 1975b), but large amounts of residue left after logging leave the areas unsightly, create fire hazards, and impede forest management activities. Of particular concern initially is managing residues so as to encourage regeneration and growth of the new forest. In this study four postlogging treatments and three regeneration methods were tested.

Postlogging treatments.—On the two blocks logged to conventional utilization standards, slash was tractor piled and burned on two separate quarters of each and was broadcast burned on the other two quarters, as described earlier. Two quarters of each residue-removed unit were left "as is" following logging and chips were spread on the other two quarters. The map in figure 4 showed the location of these treatment in each unit.

Regeneration methods.—Each quarter block was further divided into thirds for the following three regeneration treatments: (1) auger-planting 2-0 lodgepole pine seedlings, 700 per acre (1 729/ha) in 18 in (45 cm) square scalped spots; (2) spot seeding of 12 to 15 lodgepole pine seeds on about 1,000 seed spots per acre (2 500/ha) after the spots (18 in [45 cm] square) were scalped free of competing vegetation (Lotan and Dahlgreen 1971); and (3) left for natural regeneration. The study area had primarily nonserotinous cones. Planting stock came from the Lucky Peak nursery near Boise, Idaho. Seeds for both the planting stock and the seed spots had been obtained from the upper Fish Creek drainage near the study site.

Planting was done in early June, and seeding in late June, 1973. Techniques used were standard procedures recommended by the Intermountain Regional Office. Planting stock was transported from snow-cache storage each day.

The study area was fenced to keep livestock out, and pocket gophers were effectively controlled with poisoning. However, large ungulates such as moose (*Alces alces* [Nelson]), elk (*Cervus canadensis* [Bailey]), and deer (*Odocoileus* sp.) frequented the area.

Regeneration costs.—Costs of regeneration (1971 and updated to 1980) were:

	Planting		Seeding	
	1971	1980	1971	1980
	Dollars per acre			
Broadcast burn	$122.89	$219.98	$75.33	$134.84
Pile/burn	133.48	238.93	61.12	109.40
Residue-removed	156.92	280.97	66.93	119.80
Chip spread	146.00	261.34	53.05	94.96

Poisoned grain for rodent control cost $3.00/acre in 1971 ($5.37 in 1980). Fencing cost $61.50/acre in 1971 ($110.08 in 1980).

The tree survival, growth, and vegetative development were measured periodically in years following regeneration. The techniques and results of these regeneration studies are discussed later in this report.

PRIMARY RESPONSES

This section describes the initial changes in the site that occurred in connection with harvest and posttreatment activities. Ultimately, effects of harvesting are reflected in the familiar components of the forest scene—vegetation, trees, and wildlife. But underlying and preceding these are the initial changes brought about from harvesting to the microclimate, biomass, and soil and water regimen.

Biomass and Cover

Prior to harvest there were 141 to 149 tons per acre (316 to 334 t/ha) of woody material on the site, including tree crowns (duff excluded). About 90 tons per acre (202 t/ha) were removed as saw logs, and the remaining residues were burned, removed, or chipped and spread back over the site.

The amount of woody material remaining after harvest and residue treatment ranged from about 19 tons per acre (42 t/ha) on the residue-removed units to about 68 tons per acre (152 t/ha) where residues were chipped and spread back on the site. In the pile/burn treatment, residues were reduced as much as on the residue-removed treatment, but on the broadcast burns, more material remained as charred or lightly burned pieces.

The woody material weights and the percentage of change from preharvest to posttreatment are as follows:

	Pre-harvest		Post-treatment		Percent change
	Tons/acre	*(t/ha)*	*Tons/acre*	*(t/ha)*	
Residues-removed	141	(316)	19	(42)	−87
Residues chipped and spread	141	(316)	68	(152)	−52
Conventional, broadcast burn	149	(334)	34	(76)	−79
Conventional, pile/burn	149	(334)	20	(45)	−87

Measurements and estimates of understory vegetation were made in undisturbed stands and after harvesting. Before harvest there was about 400 lb per acre (448 kg/ha) of understory vegetation, most of which was destroyed in logging. After harvest and residue treatment, understory vegetation was estimated to be 50 lb per acre (56 kg/ha).

Prior to harvest, the ground cover in undisturbed stands was predominantly needles, woody material, grass, and forbs. Following harvest (prior to spreading chips or burning), grass and brush cover were virtually eliminated and mineral soil increased by 30 to 40 percent (table 2). Woody material cover also increased by about 10 percent. After burning and chip-spreading were completed, the total ground cover in those treatments was estimated as follows: chip-spread, 100 percent; broadcast burn, 80 to 90 percent; and pile/burn, 47 percent.

In the pile/burn areas the logging slash was pushed into windrows approximately 20 ft (6 m) wide. After burning, these windrows ranged from about 2 ft to 5 ft (0.6 to 1.5 m) in height. A few large round piles were somewhat deeper. Piles consisted of unburned wood plus a large amount of earth that was pushed into the pile. This is not considered good practice. These burn piles occupy about 18 percent of the total area of the units, based on photo measurements. About 500 ft^3 per acre (35 m^3/ha) of woody material 3-in (7.6-cm) diameter and larger remained in the areas between the piles.

Table 2.—Ground cover before and after harvest by treatment

Cover	Conventional		Residue-removed	
	Pre-harvest	Postharvest	Pre-harvest	Postharvest
	Percent			
Mineral soil	0.7	28.7	2.3	42.5
Needles	51.0	40.5	48.0	26.2
Woody	18.8	29.2	21.2	31.0
Grass	13.3	.5	21.9	.2
Brush	16.1	0	5.5	0
Total (rounded)	100	100	100	100

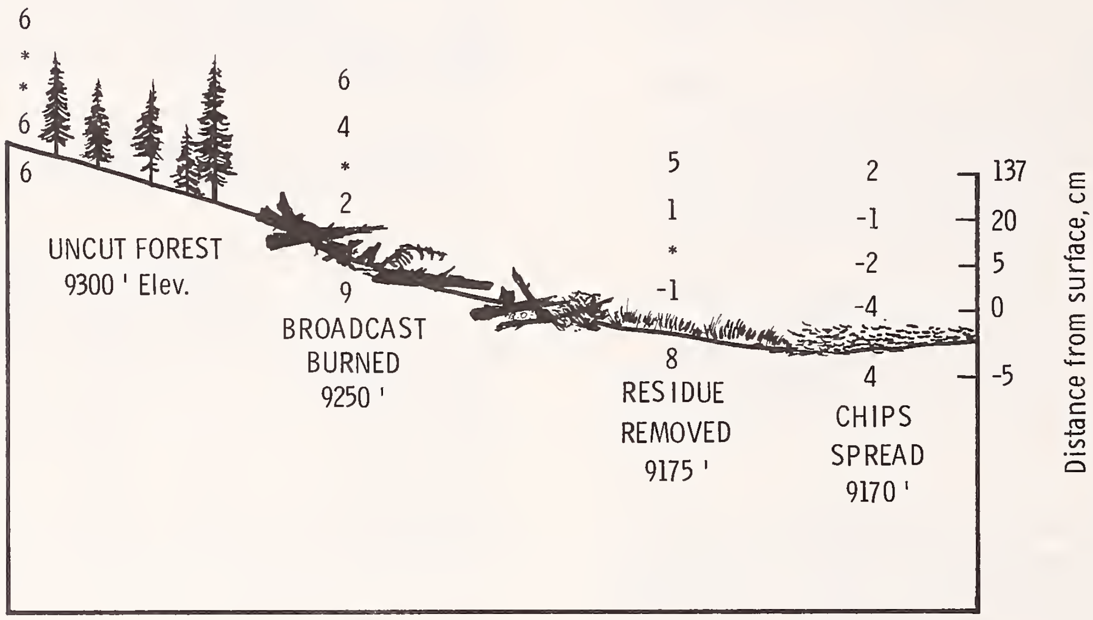


Figure 7.—Low temperatures recorded for July 15, 1979, at units 1 and 2.

Microenvironmental Effects

Roger D. Hungerford

A preliminary analysis of data in 1978 suggested that temperatures at or near the surface might influence seedling survival and growth. Beginning July 12, 1979, air temperature and soil temperature were recorded hourly at units 1 and 2 for chip-spread, residue-removed, and broadcast-burn treatments, and in the uncut forest. Net radiation was recorded hourly for the chip-spread treatment. On August 2, the recording systems were disabled by a bear but about 3 weeks' data were obtained.

Temperatures were recorded at the surface, below the surface (2, 5, 10, 20, and 40 cm), and above the surface (5, 20, and 137 cm). Because of some topograhic variations, both air drainage and residue treatment may affect temperature, and it was not possible to separate these. Nevertheless, the temperatures recorded can be used in analyzing seedling survival and growth.

Figure 7 shows a profile across the site for July 15, and illustrates typical low-temperature relationships. The uncut forest and the broadcast burn-treatment, both of which were upslope, had slightly warmer temperatures than did the residue-removed and chip-spread treatments, which were at a lower elevation in the particular unit measured.

On all treatments, temperatures were coldest at the surface, progressively warmer at distances above the surface, and warmest below the surface.

Both high and low temperatures have been reported as causing lodgepole pine seedling mortality. Cochran and Bernsten (1973) reported that lodgepole pine seedlings can tolerate low growing season temperatures of −9° C, but first-year seedlings are particularly susceptible. By mid-growing season −8° C caused 70 percent mortality and −5° C caused 20 percent mortality. High temperatures of about 52° C caused death of plant cells (Hare 1961; Baker 1929), but Lotan (1964) reported seedlings can survive surface temperatures of 60° C for short periods because temperatures of cambial cells do not rise above 52° C.

At the study site only the chip-spread treatment had temperatures −8° C or colder: this low was reached on 20 percent of the nights, for an average duration of 0.65 hour.

The −5° C threshold was reached on both the chip-spread and residue- removed treatment, and freezing temperatures (< 0° C) were reached in all harvested treatments but not in

Table 3.—Frequency and duration of temperatures <0° C and ≤-5° C on units 1 and 2 in summer 1979, by treatment and height above surface

	Frequency							
	Percent of days <0° C				Percent of days ≤-5° C			
Treatment	Surface	5 cm	20 cm	137 cm	Surface	5 cm	20 cm	137 cm
Chip-spread	85	75	60	5	45	20	5	0
Residue-removed	65	45	20	0	10	—	0	0
Broadcast burn	10	—	0	0	0	—	0	0
Uncut	0	—	—	0	0	—	—	0
	Duration							
	Mean h/day <0° C				Mean h/day ≤-5° C			
Treatment	Surface	5 cm	20 cm	137 cm	Surface	5 cm	20 cm	137 cm
Chip-spread	5.3	3.0	1.8	0.05	1.6	0.6	0.05	0
Residue-removed	3.0	—	.8	0	.5	—	0	0
Broadcast burn	.2	—	0	0	0	—	0	0
Uncut	0	—	—	0	0	—	—	0

the uncut forest. Low temperatures and their duration are summarized in table 3.

Surface temperatures were low enough to expect substantial seedling mortality on the chip-spread treatment and some mortality on the residue-removed treatment. Actual survival and growth of seedlings support these predictions. In five growing seasons, planted seedlings suffered 76 percent mortality in the chip-spread treatment and 46 percent mortality on the residue-removed treatment in unit 1.

Topography as well as treatment may have contributed to low temperatures in units 1 and 2. In unit 4, mortality for chip-spread was about 30 percent and for residue-removed, 20 percent. This unit was not continually monitored for temperature, but all treatments were on a slope that would not trap cold air, and low threshold temperatures were less likely. Survival and growth of seedlings are discussed in more detail in later sections.

Surface temperatures of 58° C were recorded on the residue-removed and broadcast-burn treatments, and 53° C on the chip-spread treatment during the period. On all three treatments, temperatures of 50° C or higher were sustained 2 hours or more for at least some of the days. Such temperatures would not likely cause significant damage or mortality to the planted seedlings.

Net radiation was higher above the broadcast-burn and residue-removed treatments than above chip-spread or pile/burn treatments. This indicates greater reflectivity on the latter treatments, and could increase leaf temperatures on seedlings. This potentially could increase transpiration.

Soil Properties and Nutrients

Norbert V. DeByle

For more than 5 years, scientists sampled physical and chemical soil parameters, soil solution chemistry, overland flow and erosion, vegetative cover and biomass, and associated parameters on the study area to evaluate treatment effects on soil fertility, site quality, erosion, and water quality. Soil samples for chemical analyses were taken at the initiation of the treatments and again 5 years later (DeByle 1980). Samples were analyzed for pH, cation exchange capacity, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), zinc (Zn), iron (Fe), and sodium (Na).

The physical soil parameters, vegetative cover, runoff, and erosion were sampled and measured in 1973, 1975, and 1977 (Packer and Williams 1980). In each of these years, 60 infiltrometer plots (48 on the clearcut tracts and 12 in the adjacent unlogged forest) were treated with a rainfall simulator that applied water at a constant rate of 8.2 cm/h (3.2 in/h). Vegetal characteristics and soil cover were measured with a point analyzer on 100 points within each plot. Soil solution samples were withdrawn from depths down to 4 ft (1.2 m) at several locations and times during each growing season (Hart and others 1981). These solutions were analyzed for contents of K, Ca, Mg, Na, nitrate-N, phosphate, total phenols, and electrical conductivity.

Five planted and five seeded lodgepole pine trees were taken from each quadrant of each unit in 1977 and dissected into five components (DeByle 1980). Each component was weighed and analyzed for contents of N, P, K, Ca, Mg, Zn, Fe, B, Na, and ash.

SURFACE ORGANIC LAYER

Harvesting and slash disposal left markedly different physical conditions on the surface layer. After treatment the amounts of litter and debris less than 1.2-in (3-cm) diameter remaining on the soil surface, and thus making up the A_0 horizon were:

	Litter weight		Litter depth	
	Lb/acre	*(kg/ha)*	*In*	*(cm)*
Uncut forest (control)	31,667	(35 494)	1.02	(2.6)
Broadcast burn	31,220	(34,995)	.71	(1.8)
Pile/burn (under piles)	28,537	(31,985)	.67	(1.7)
Pile/burn (between piles)	29,641	(33,222)	.51	(1.3)
Residue-removed	37,662	(42,213)	.94	(2.4)
Chip-spread	161,124	(180,592)	~~46.1~~ 4.61	(11.7)

The quantity and depth of litter on the chip-spread treatment was highly significantly different from all others.

The nutrient content of the surface organic layer also

Table 4.—Nutrient content of the surface organic (A_o) horizon

Nutrient	Year	Uncut forest	Broadcast burn	Pile/ burn (under)	Pile/ burn (between)	Residue-removed	Chip-spread
		Lb/acre (kg/ha)					
Nitrogen	1972-73	412 (462)	311 (349)	115 (129)	309 (346)	273 (306)	—
	1977	450 (504)	398 (446)	257 (288)	272 (305)	409 (458)	508 (569)
Phosphorus	1972-73	30 (34)	50 (56)	46 (52)	28 (32)	37 (41)	—
	1977	35 (39)	34 (38)	28 (32)	24 (27)	34 (38)	69 (78)
Potassium	1972-73	66 (96)	105 (118)	107 (120)	70 (79)	118 (132)	—
	1977	61 (68)	59 (66)	45 (51)	45 (50)	65 (73)	148 (166)
Calcium	1972-73	156 (175)	284 (318)	310 (347)	115 (129)	168 (188)	—
	1977	299 (335)	374 (419)	320 (359)	196 (220)	267 (299)	408 (457)
Magnesium	1972-73	54 (61)	94 (105)	96 (108)	80 (90)	87 (98)	—
	1977	73 (82)	75 (84)	57 (64)	54 (61)	69 (77)	165 (185)
Sodium	1972-73	—	—	—	—	—	—
	1977	4 (5)	4 (4)	4 (4)	3 (3)	4 (4)	10 (11)

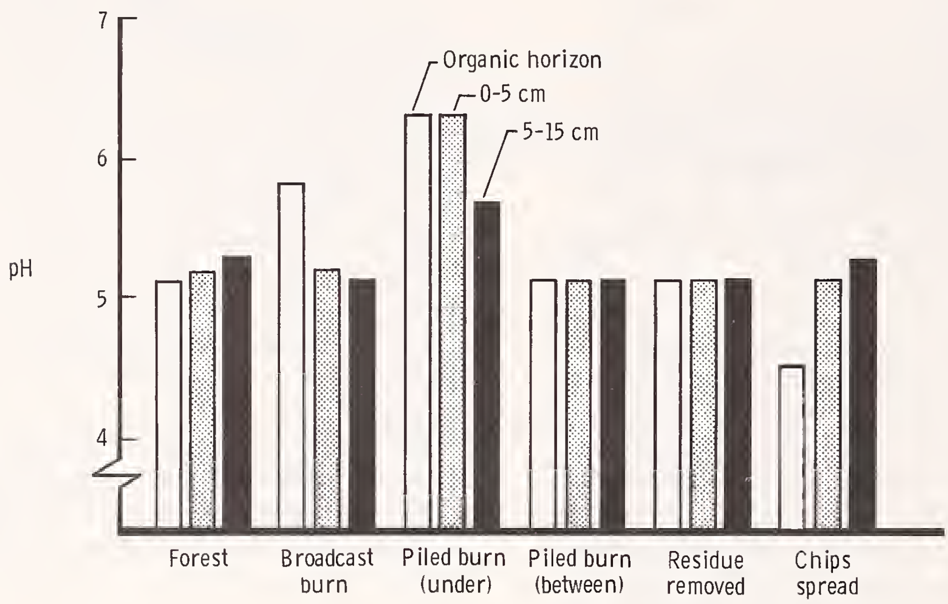


Figure 8.—Soil pH 5 years after treatment.

changed as a result of treatment. Over the 5-year timespan there was an increase in the N and Ca contents and a decrease in the K and Mg contents of this horizon (table 4). Even though chips had a lower concentration of most elements than did the litter in the uncut forest, their large volume on the chipped-returned site, plus the residual litter beneath, resulted in a larger quantity of every nutrient on this treatment than on any other. After 5 years, total N content was least (228 kg/ha) under burned piles; K content was lowest (50 kg/ha) both under and between piles. Phosphorus seemed unaffected by treatments. Residue removal as well as burning the slash initially increased the contents of K and Mg in the surface organic layer by approximately one-third. But, 5 years later these had returned to near the values found in the undisturbed forest, 68 and 82 kg/ha, respectively.

MINERAL SOIL

The pH of each layer of soil sampled in 1977, 5 years after treatment, is illustrated in figure 8 (DeByle 1980). Mineral soil pH under all but one of the treatments was essentially the same, averaging 5.2. Under the burned piles it was markedly higher—6.4 in the 0- to 5-cm depth and 5.7 in the 5-to 15-cm depth. The pH of the organic surface horizon was less uniform. It was 5.8 and 6.4 in the ash-litter-duff mixture on the broadcast-burn and pile/burn treatments, respectively, still reflecting the changed physical conditions and the release of cations triggered by burning 5 years earlier. In contrast, the slowly decomposing chip mulch had a pH of 4.6, more acidic than the underlying mineral soil.

The year after burning, in 1973, the pH at various soil depths under the burned piles was: A_o horizon 7.2; 0 to 5 cm, 6.5; and 5 to 15 cm, 5.3. In the areas broadcast burned 2 months before sampling, pH was 6.2, 4.8, and 5.0 at the same depths. Burning immediately changes the pH of the

Table 5.—Percentage of organic material in mineral soil

Treatment	Depth and year			
	0-5 cm[1]		5-15 cm	
	1972-73	1977	1972-73	1977
Forest	6.0	5.2	3.4	2.2
Broadcast burn	7.2	5.9	3.5	2.4
Pile/burn (under)	6.9	4.1	4.4	2.8
(between)	7.1	4.6	3.7	2.6
Residue-removed	6.6	5.9	4.5	2.2
Chip-spread	7.1	8.6	4.6	2.2

[1]Average of Packer and William (1980) and DeByle (1980) observations.

organic surface layer. Leaching of soluble material from that layer by subsequent precipitation later raises the pH of the mineral soil beneath. Those changes were present a year after burning and have remained for several years. Other treatments did not significantly change mineral soil pH.

The organic matter content of the 0- to 5-cm layer of undisturbed forest soil ranged between 5 and 6 percent (table 5). In the 5-to 15-cm layer it was half this concentration. Treatments changed the content of organic matter in the surface 5 cm. In 1977 the highest organic matter content, 8.6 percent, occurred where the logging residue had been returned as a mulch of chips. The lowest organic matter content, 4.1 percent, occurred beneath burned windrows. During the 4-year period the organic matter content of the mineral soil increased where the residue treatments did not involve burning and decreased where burning was part of the disposal treatment. Disturbance caused by logging, thus breaking up fine organic debris in the A_0 horizon and incorporating it into the mineral soil beneath, likely caused the initial increase in organic matter content. Burning and decomposition of organic material in the soils no doubt resulted in the later decline on most treatments. During this time, a decrease would be expected because new plant growth added little organic matter to the soil on these clearcut sites.

As the content of organic matter varies, so will the content of total nitrogen. Total N supply in 1977 in the upper 15 cm of mineral soil varied from 2 000 kg/ha under the undisturbed forest to more than 2 600 kg/ha under the broadcast burn (DeByle 1980). Per unit of depth, there was almost twice as much N in the 0- to 5-cm layer of soil than in the 5- to 15-cm layer. The quantity of N available for plant growth has very limited relationship to total supply. Instead, available N varies with nitrification rates and, hence, depends upon microbiological activity. This is discussed in later sections. (See also Schmidt and Lotan 1980; Jurgensen 1980.)

Available P was almost twice as abundant in the upper 15 cm of mineral soil 5 years after logging than it was in the undisturbed forest. The largest quantity (64 ppm) was found under the chip mulch, with the next largest amount (58 ppm) under burned piles. That between burned piles, in contrast, was not significantly different than the forest. Extractable K was greatest (0.63 meq/100 g) in 1977 in the mineral soil under the burned piles of debris. The mineral soil in the forest had only 0.45 meq per 100 g of K. Extractable Ca was slightly increased by the logging operation. The soil under the burned piles contained twice as much Ca (9.4 meq/100 g) as did the undisturbed forest. Extractable Mg quantity followed the same pattern. Zinc was more than twice as concentrated (7.4 ppm) under burned debris piles than on any other treatment. Broadcast-burned sites were also slightly elevated in Zn concentration. The most Fe was found under chip spread (445 ppm), where it was twice as concentrated as it was in the undisturbed forest. The soils under burned piles had 304 ppm Fe, the next greatest concentration.

The cation exchange capacity of the surface 5 cm of mineral soil averaged 18.63 meq per 100 g and that of the 5- to 15-cm layer averaged 15.27 meq per 100 g. In 1977, four cations (K, Na, Ca, and Mg) occupied a bit less than one-half of this capacity in the undisturbed forest, about half under four of the treatments, and nearly three-fourths of the total cation exchange capacity under the burned piles. This indicates that nutrients released by decomposition and burning are, in fact, being caught and held within the soil mantle.

The bulk density of the surface 5 cm of soil in 1973 was greatest where the chip mulch had been recently applied (Packer and Williams 1980). This was probably caused by compaction from tractors used to spread the chips. The next highest bulk densities occurred between windrows, also probably related to tractor compaction. In 1977, the highest bulk densities were found between windrows and the lowest in the unlogged forest. In the interim, soil bulk densities improved (decreased) on the residue-removed utilization units. In contrast, bulk densities remained high under the pile/burn treatment.

Total porosity of the soil is the converse of bulk density. The more porous the soil, the lower its bulk density. Also, other factors being equal, the greater will be its capacity for infiltration and percolation of water. By 1977, the greatest porosity was encountered in the unlogged forest and the lowest between windrows, the very sites where bulk density was lowest and highest, respectively (fig. 9).

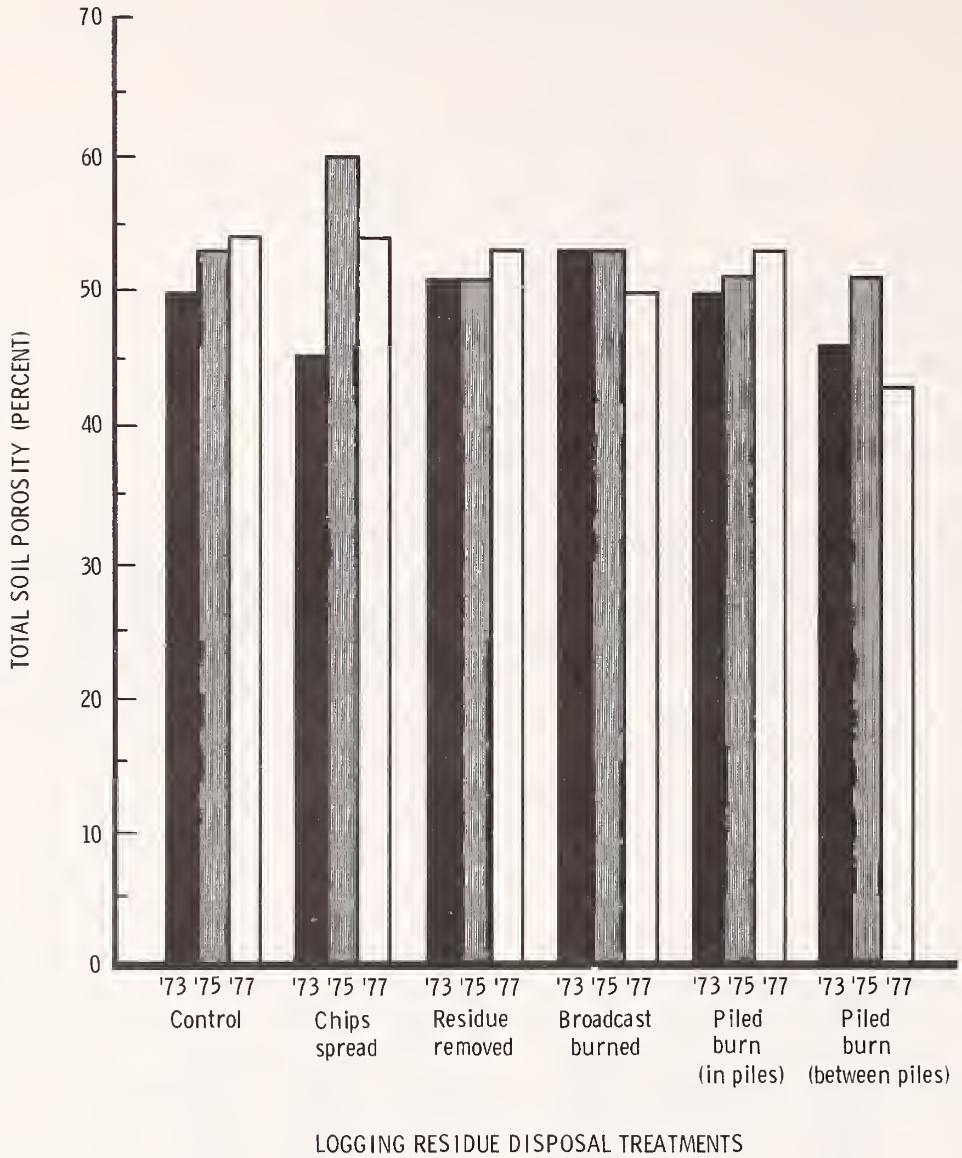


Figure 9.—Total porosity of the surface 2 inches of soil associated with various residue treatments on lodgepole pine clearcuts.

SOIL SOLUTIONS

From 1972 through 1977, more than 600 samples of soil solutions from 44 tubes under 6 treatments were analyzed (DeByle 1980; Hart and others 1980). The average concentrations of nutrients in the soil solutions under the control (uncut forest) and the treatment yielding the highest concentrations (under the burned piles) are shown in the following tabulation:

Nutrient	Forest	Pile/burn (under)
	Mg/liter	*Mg/liter*
Potassium	0.6	2.0
Sodium	1.4	2.2
Magnesium	.7	3.3
Calcium	2.6	11.9
Nitrate-nitrogen	.1	4.4

Potassium concentrations increased under the chip mulch and under both burning treatments. Sodium increased, too, especially under burned piles. Higher concentrations of magnesium were observed under both the chip-spread and the burns. Levels of calcium increased and persisted under all treatments. Most residue disposal methods produced greatly increased concentrations of nitrate-nitrogen. Increases varied from twofold to a hundredfold, with some samples approaching a concentration of 10 mg/liter. Clearcutting alone interrupts the nutrient cycle and may increase nutrient concentrations in the soil solution. Leaching of logging debris also contributes nutrients. Conditions present after an intense fire in large concentrations of fuel, such as beneath windrows, further elevate concentrations of some nutrients.

Nutrients held in the biomass that remain on the site after harvest are either slowly released through decomposition, or rapidly released or converted to a soluble form by burning. Some of these released nutrients are lost from the site; some are held within the mineral soil to be removed by developing vegetation. As the forest develops and matures, nutrient cycling again will occur much as it did in the stand that was harvested. Prior to establishment of a complete vegetative cover, we can expect greater nutrient losses in runoff waters. Most losses occur immediately after treatment, especially if burning is applied. The concentration of nutrients in the soil solutions are indicative of what might be lost from the site during the first 5 years. These in-

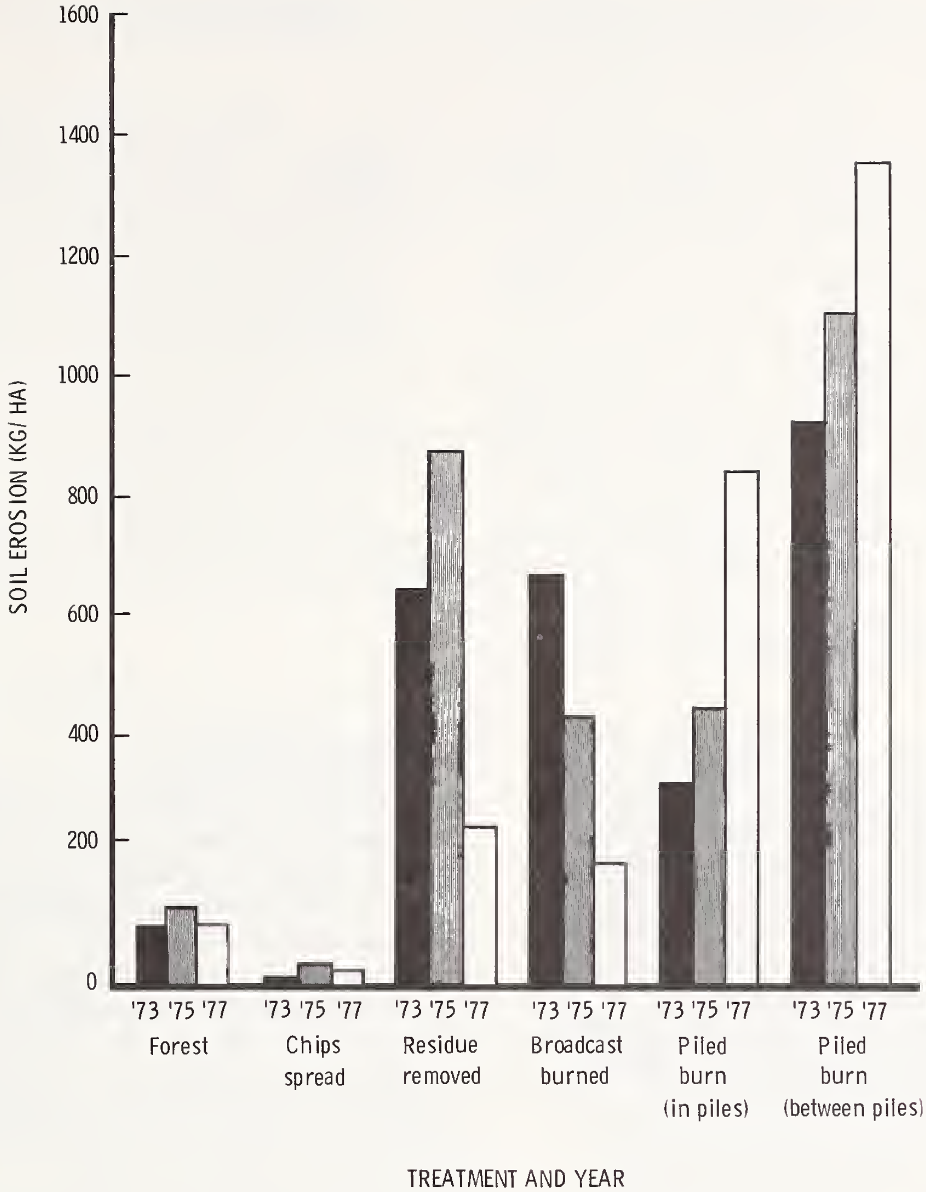


Figure 10.—Soil erosion infiltrometer plots on all treatments in 1973, 1975, and 1977.

creased nutrient levels most likely will diminish to those levels found in the uncut forest within the next 5 years. Nitrate-nitrogen may be an exception—the increased nitrification that perhaps is associated with herbaceous vegetation may occur until the forest becomes fully reestablished. Until that time, increased nitrate levels may exist in the soil solutions. With the exception of increased nitrates, none of the treatments produced nutrient changes in the soil and water that should concern the manager. Some of the highest nitrate concentrations measured in the soil solution, if they reached the ground water or stream without further dilution, would be considered a pollutant in a public water supply where the maximum concentration allowed is 10 mg/liter.

Total phenol concentrations in the soil solution ranged from practically none under undisturbed conditions to 0.666 ppm under chip-spread and to 0.188 ppm under the residue-removed treatment during the first year. Thereafter they declined markedly. Such organic compounds appear to readily leach from finely divided conifer debris, especially chips. During the first year they were found in the soil solution under some treatments in concentrations that could reduce plant growth. Phenolics released from plants are believed to be a cause of allelopathy (Fisher 1980).

Phenolic compounds flushed into the soil solution from the residue-removed units, particularly from under the chip mulch, are a potential pollutant. This flush occurs only during the first year or two after treatment, but the concentrations far exceeded allowances for public water supplies (0.001 ppm). Also, the phenolics may have contributed to the stunted seedling growth on the chip-spread area. Both possibilities should concern the forest manager; however more research is needed to determine if our concerns are valid.

SURFACE HYDROLOGY AND SOIL STABILITY

Surface runoff (overland flow) from the infiltrometer plots was least on the chip-spread treatment. Here only 20 to 25 percent of the rainfall applied was collected as surface runoff (Packer and Williams 1980). Although there was wide variation among the years of sampling, by 1977 the broadcast-burned sites had a similarly small amount of overland flow. In both instances, runoff was about half the amount produced in the unlogged forest. Largest amounts of overland flow occurred between

Table 6.—Soil microbial populations in the surface 0- to 5-cm mineral soil layer[1]

Year	Control	Chip-spread	Residue removed	Burn treatments: Broad-cast	Piled: Between	Piled: Under
Bacteria ($\times 10^6$)						
1972	3.2	—	10.9	—	—	—
1976	12.0	4.1	4.7	10.4	3.0	2.6
Streptomyces ($\times 10^5$)						
1972	7.5	—	20.4	—	—	—
1976	4.2	1.2	2.0	6.0	2.0	5.2
Fungi ($\times 10^5$)						
1972	2.3	—	9.0	—	—	—
1976	2.8	1.2	3.5	2.7	0.4	2.3

[1]From Skujins, see text footnote 2.

windrows where residues as well as some vegetation and soil had been removed by dozer piling. Here two-thirds of the water applied was caught as surface runoff; only one-third infiltrated.

The amounts of soil erosion measured on these infiltrometer plots for the 3 years of record are shown in figure 10 (Packer and Williams 1980). In each year, less than 45 kg/ha eroded from the chip-spread treatment, much less than from the unlogged control sites. The largest amounts of erosion—in excess of 1 340 kg/ha—occurred between windrows in the pile/burn treatment. With the exception of areas mulched with chips, erosion was least where residue was broadcast burned.

From the standpoint of overland flow and soil erosion, the most effective residue treatment is chipping and respreading these chips as a protective mulch. Nevertheless, this treatment has serious disadvantages—almost complete suppression of vegetation and elimination of natural forest regeneration for at least 5 years and perhaps up to 20 years after application. The most adverse overland flow and erosion were encountered where residue was dozer-piled and burned. Recovery rates here were slow during the first 5 years, but the forest will probably become reestablished on this treatment faster than on any other. A closed-canopy lodgepole pine forest again will provide adequate watershed protection. One of the least detrimental residue disposal treatments in terms of watershed condition, performance, and speed of recovery during the first 5 years is residue-removed treatment. On this treatment, however, herbaceous vegetation may have to supplant the much more slowly developing lodgepole pine forest for watershed protection during the next several decades.

From the standpoint of economics and practicality, broadcast burning after conventional clearcutting provides fairly rapid return to preharvest conditions and suitable forest regeneration. In general, impaired watersheds do not rapidly recover at the high altitudes and short growing seasons that characterize these forests. Sites where the vegetation and soil mantle have been drastically disturbed by mechanized equipment recover more slowly than similar sites where residue disposal did not disturb the forest floor.

Soil Microorganisms

Martin Jurgensen, Alan E. Harvey, and Michael J. Larsen

Soil microflora influence the continued productivity of the forest ecosystem. The activities of these organisms are strongly affected by various silvicultural or logging programs (Jurgensen, Larsen, and Harvey 1979). Timber harvesting directly influences soil microorganisms by removing organic matter from a site as logs or pulpwood, and by postlogging site preparation techniques such as burning and soil scarification. Organic matter decomposition is affected by soil chemical and physical changes following these operations (Harvey and others 1976). The decomposition of organic matter, both in the litter layer and mineral soil, by soil microorganisms is a key factor in the cycling of many soil nutrients. Nitrogen availability is especially sensitive to changes in microbial activity. Nearly all of the nitrogen in forest soils is present in organic form (Jurgensen and others 1980). Consequently, any study on the environmental impact of harvesting and residue utilization programs must consider effects on soil biological properties.

With the cooperation of various groups of Forest Service and university scientists, the numbers and activities of soil microorganisms were monitored on the study plots. Populations of bacteria, streptomyces and fungi, carbon dioxide evaluation rate (respiration), dehydrogenase and protease activity, and the levels of ammonium and nitrate were measured in the soil before and at various times after the site treatments. Details of the sampling design and methodology are given by Skujins.[2] An estimate of nonsymbiotic nitrogen fixation rates was made in July 1978 using the acetylene reduction technique described by Larsen and others (1978). Five soil cores were taken from each plot using an impact sampler (Jurgensen and others 1977). Chip-spread layer and chip piles left on the site were also sampled for nitrogen-fixing activity and chemical composition. In addition, the number of mycorrhizal root tips in the uncut control stand was compared to such root tips in other timber types in the Northern

[2]Skujins, John. Effect of modified slash disposal practices on the biochemistry of soils. Office report, study FS-INT-1203. Missoula, MT: Forestery Sciences Laboratory; 1977.

Rocky Mountain region. Mycorrhizal root counts were taken from 50 soil cores using the methods described by Harvey and others (1979).

SOIL MICROBIAL PROPERTIES

Populations of soil microorganisms responded to logging and the resulting opening up of the stand in the year (1972) following harvesting (table 6). Three to four years later, however, numbers were similar among the various postharvesting treatments. Bacteria populations generally appeared lower in the treated plots as compared to the uncut control, but a large variation in counts coupled with a limited sample precluded meaningful statistical analysis.

The effects of timber and residue removal on soil biochemical activities are illustrated by the respiration rates as shown in table 7. No pattern of response was evident among site treatments, although year-to-year differences were apparent. Similar results were found with the dehydrogenase and protease enzyme assays.

NITROGEN MINERALIZATION

In contrast to microbial population and biochemical results, decided treatment effects were noted in soil nitrogen transformations. Soil nitrate levels were uniformly low in the uncut stand during the 5-year study period. This contrasts with the higher nitrate concentrations found in all treated plots (table 7). The greatest nitrate responses were associated with broadcast burning and woodchip spreading in the year following treatment. Increased soil nitrate levels were still found in the broadcast-burn sites 3 years after the fire. High nitrate concentrations were also found in subsurface water samples by Hart and DeByle (1975) following the broadcast burn.

An inhibition of nitrification was evident in the soil beneath the slash piles, at least for the first year after they were burned. By the end of 3 years, however, appreciable amounts of soil nitrate were being produced. Hart and others (1981) found the highest nitrate concentrations in the subsurface water samples beneath the burned slash piles.

Soil ammonium concentrations varied considerably over the 5-year study period. Other than a sizable increase following burning, no discernible ammonium/treatment effects were evident (table 7). Nevertheless, similar to the biochemical assays, ammonium level fluctuated from year to year, particularly in 1976.

Increased soil nitrogen mineralization frequently occurs following timber harvesting, particularly if associated with a burning treatment (Mroz and others 1980). Such fire-related changes in microbial activity are attributed to the release of available carbon, ammonium, and mineral nutrients from the burned organic matter, and to a resultant decrease in soil acidity. Increased soil nitrogen mineralization rates reported on cut but unburned sites are likely due to more favorable soil moisture and temperature regimes, or to a removal of mycorrhizal fungal inhibition on soil microorganisms (Gadgil and Gadgil 1978; Wells and others 1979).

NITROGEN FIXATION

The microbial conversion (fixation) of inert atmospheric N_2 into usable forms is an important process in the replacement of nitrogen lost from a site due to timber harvesting or fire (Jurgensen and others 1980). Because most nitrogen-fixing organisms require organic substrates as energy and carbon sources, their activity would likely be favored in soil organic layers. Such an effect was shown in this study by the high nitrogen-fixation rates in the woodchip layer (table 8). Overall, nitrogen-fixation rates were highest in the uncut control stand, perhaps because of a more favorable soil climate or because of the activity of nitrogen-fixing microorganisms around plant roots (rhizosphere effect).

Table 7.—Effect of site treatment on respiration rates, and nitrate and ammonium concentrations in the surface 0- to 5-cm mineral soil layer[1]

				Burn treatments		
					Piled	
Year	Control	Chip-spread	Residue removed	Broad-cast	Between	Under
Respiration	*Moles CO_2/gm of soil/minute*					
1972	[2](203)	—	91	—	—	—
1973	68	74	42	85	16	44
1974	54	40	24	24	23	10
1976	20	21	21	12	7	19
Nitrate	*Mg/liter*					
1972	(1.1)	—	0.6	—	—	—
1973	.6	2.2	1.7	5.3	(8.7)	(0.7)
1974	.6	11.6	3.0	22.0	9.6	.7
1976	.4	.3	2.0	10.3	.4	6.3
Ammonium	*Mg/liter*					
1972	1.1	—	2.3	—	—	—
1973	7.2	3.7	9.4	43.3	7.6	17.8
1974	11.2	5.8	5.4	14.5	2.1	6.1
1976	61.0	13.4	36.8	28.2	16.3	18.8

[1]From Skujins, see text footnote 2.
[2]Parentheses indicate value based on only one sampling during the growing season. Other values based on three sample collections.

Table 8.—Soil N-fixation rates as affected by site treatment

Soil strata	Control	Broadcast burning	Residue-removed	Chip-spread
	Grams N fixed/gram of soil/day ($X10^{-9}$)			
Surface organic layer (O_2)	2.1	0	0	[1]70.8
Decayed soil wood (O_3)	35.9	8.2	17.6	[2]
Mineral soil 0 to 5 cm	2.7	.7	.9	.9
5 cm to core bottom	.8	< .1	.2	.1

[1]Average value of nitrogen fixation in woodchip layer.
[2]Due to the presence of the chip layer decayed soil wood could not be located and sampled.

Table 9.—Amounts of N fixed per hectare per day as affected by site treatment

Soil strata	Control	Broadcast burning	Residue-removed	Chip-spread
	Grams			
Surface organic layer (O_2)	0.1	0	0	[1]11.3
Decayed soil wood (O_3)	0.2	0.1	0.1	[2]
Mineral soil 0 to 5 cm	2.1	.6	.7	.7
5 cm to core bottom	2.0	.2	.5	.3
Total	4.3	.8	1.3	12.3

[1]Average value of nitrogen fixation in woodchip layer (table 10).
[2]Due to the presence of the chip layer decayed soil wood could not be located and sampled.

When the weight/volume relationship of each soil fraction is used to calculate total amounts of nitrogen added to each site, a different perspective is obtained (table 9). Even though the nitrogen-fixing rates were much lower in the mineral than in the organic soil layers, the greatest nitrogen gains occurred in the mineral horizons. This is due to the high mineral/organic ratio in this soil. The only exception was in the chip-spread treatment, which had appreciable N gains in the chip layer.

These results indicated that timber harvesting reduced the amount of nitrogen added to these sites by nonsymbiotic nitrogen fixation, especially when a postharvest burning treatment was used. If it is assumed that in this high elevation soil the nitrogen-fixing microflora is active for only 100 days per year, less than 0.25 kg per ha per year of nitrogen would be added to the burned sites, and only 0.5 kg per ha per year to the uncut control. This compares with nitrogen gains of over 2 kg per ha per year in an uncut, highly productive northern Idaho cedar-hemlock timber type (Jurgensen and others 1980). Although these nitrogen additions are quite small on an annual basis, the significance over a stand rotation of 150 to 200 years would be appreciable. Nitrogen-fixation rates would likely increase as the stand becomes reestablished, but the length of the recovery period is unknown.

Symbiotic nitrogen-fixing plants, such as *Ceanothus, Alnus, Lupinus,* and *Astragalus* are also potentially significant sources of nitrogen on these sites. The occurrence and activity of these plants in Northern Rocky Mountain forest ecosystems appear to be small in most older stands, but may be significant following stand reestablishment (Jurgensen, Arno, and others 1979). Several species of lupine were the only nitrogen-fixing plants present on the study site prior to most residue treatments (Schmidt, personal communication). Lupines have been found to respond to burning treatments in Wyoming aspen stands (Bartos and Mueggler 1979). Whether they do the same in lodgepole pine following prescribed burning or other postharvesting practices remains to be seen.

The nitrogen gains associated with the woodchip treatments were higher than expected (table 10). Nitrogen-fixing activity was, by far, the greatest in the chip piles. In the chip-spread treatment nitrogen gains were greater in the chip layer closer to the mineral soil than near the surface. Such a nitrogen fixation/depth relationship is likely due to the insulating properties of the chips, which maintain a favorable moisture and temperature regime for microbial activity. A similar trend is also shown in the woodchip decay pattern, as indicated by lignin and carbohydrate levels (table 11). The greater the depth in the chip layer, the greater the loss of wood carbohydrates and a proportional increase in the more decay-resistant lignin component. Because the woodchips have a high carbon/nitrogen ratio, it is unlikely that much of the nitrogen fixed in the chip layer would be available for immediate plant use. As the decay process continues, however, this added nitrogen would slowly be released and used by the trees later in the rotation.

ECTOMYCORRHIZAE

The development of a viable mycorrhizal fungi/tree root association is an important link in maintaining stand productivity. Soil moisture, temperature,and organic matter levels influence the activity of ectomycorrhizae in Northern Rocky Mountain timber types (Harvey, Larsen, and Jurgensen 1980).

Table 10.—Nitrogen fixation associated with woodchip decay

Chip treatment	N fixed/gram dry wood/day	N fixed/hectare/day[1]
	Grams $X10^{-9}$	*Grams*
Spread		
Surface 5 cm	8.9	[2]11.3
Bottom 5 cm	132.7	
Piled	[3]447.3	63.4

[1]N gains based on a chip volume of 360 cubic meters per hectare.
[2]N gain an average of top and bottom chip N-fixation values.
[3]Samples taken from a 46-cm depth in the chip pile.

Table 11.—Lignin and total carbohydrate levels of woodchips at different depths in the chip layer[1]

Depth in chip layer	Lignin[2]	Total carbohydrate
Centimeters	*Percent*	
0- 2	$27.9^{a}(\pm 0.8)$	$65.1^{x}(\pm 1.6)$
10-12	$30.2^{b}(\pm 2.1)$	$63.1^{y}(\pm 2.5)$
[3]24-26	$32.2^{c}(\pm 2.1)$	$59.5^{z}(\pm 3.1)$

[1]Lignin and carbohydrate concentrations were determined using the methods of Moore and Johnson (1967).
[2]Values not showing a letter in common are significantly different, $\alpha = 0.05$; n = 25.
[3]Directly above the soil surface.

Table 12.—Average number of active ectomycorrhizae in 50 soil cores (10 by 30 cm) taken from the uncut control stand[1]

Soil strata	Average horizon thickness	Mycorrhizae/ core	Mycorrhizae/cm of horizon
	Centimeters		
Litter (O_1)	0.6	0.6	1.0
Humus (O_2)	.9	11.2	11.9
Decayed soil wood (O_3)	.2	2.0	8.2
Mineral soil, 0-5 cm	5.0	44.2	8.8
5 cm to core bottom	23.7	8.9	.4

[1]Sampled in the first week of July 1978.

Such soil parameters are affected by timber removal and post-harvest site treatments, which could influence the development of ectomycorrhizae on subsequent regeneration (Harvey, Jurgensen, and Larsen 1980). Consequently, basic information was needed on the distribution and activity of ectomycorrhizae in this lodgepole pine ecosystem.

The strong effect of organic matter in promoting ectomycorrhizae development found in other timber types (Harvey, Larsen, and Jurgensen 1980) was not as evident in this stand (table 12). Expressed either as actual root counts or as a percentage (fig. 11), ectomycorrhizal tips were most numerous in the mineral soil. A more favorable ectomycorrhizal response to organic matter is seen where root tip counts are compared on the basis of uniform horizon thickness (mycorrhizae/centimeter of soil layer). Even here, however, the surface mineral horizon is as good a substrate for ectomycorrhizae development as the organic layers. The high activity of ectomycorrhizae in mineral soil is likely due to the relatively moist climate and, probably of greater importance, to the low level of soil organic components. This is best seen in the very low amounts of decayed soil wood in the soil and is related to the frequent fire history in this timber type. Whether the addition of organic matter to the soil as woodchips would affect mycorrhizal development remains to be seen.

LONG-TERM IMPLICATIONS

The timber harvesting and subsequent residue-removal treatments imposed on this lodgepole pine site had significant impacts on soil biological properties. Most affected were the soil organisms involved in soil nitrogen transformations. Increased nitrification in the years following treatment, particularly after a

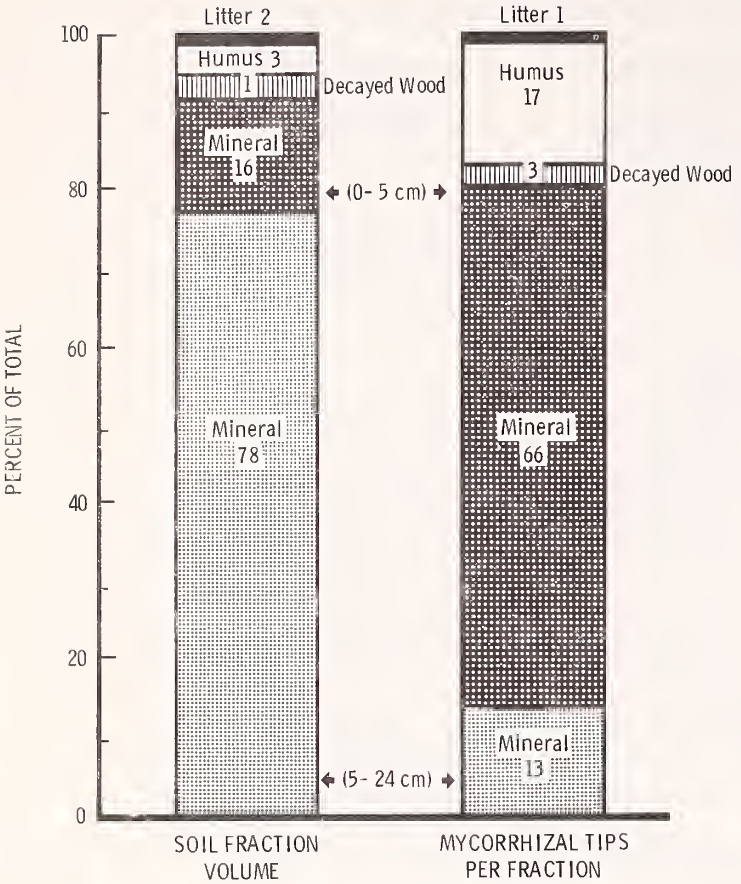


Figure 11.—Relationship of soil fraction to ectomycorrhizal occurrence.

postharvest burn, could enhance nitrogen uptake by subsequent regeneration. Increased nitrogen leached from the site also resulted from increased nitrogen availability. Whether this nitrogen loss, coupled with the nitrogen lost in timber and residue removal, would affect continued stand productivity will depend on the nitrogen status of the soil and the amounts of nitrogen added to the site through rainfall and nitrogen fixation. Such inputs of nitrogen from nonsymbiotic nitrogen fixation were reduced as a result of most site treatments. The fixation rate was so low in the uncut forest soil, the decrease in harvest units may not be significant. The only exception was when the residue was chipped and spread on the site. In this case appreciable amounts of nitrogen were fixed, but the advantage of such a residue conversion is unclear because no comparison can be made to nitrogen gained if the residue was left intact on the site. Of greater importance to soil nitrogen levels may be the establishment of nitrogen-fixing plants, such as lupines, in the stand following harvest. The chip-spread treatment would probably have been more effective in adding nitrogen if small, discrete piles had been scattered over the site (Blanchette and Shaw 1978). This intervening mineral soil also would provide for warming and to serve as a seedbed for regeneration.

In contrast to the biological nitrogen transformations, soil microbial populations and biochemical activities were little affected by the treatments applied. This may be due to a lack of sensitivity in the methods used or to inadequate sampling. The predominance of mycorrhizae in the surface mineral soil of the uncut stand would indicate that soil organic levels may not be as important to mycorrhizae development in lodgepole pine as in other timber types. Nevertheless, this does not mean that stand productivity on these sites cannot be improved by increasing the soil organic component through appropriate residue treatments or fire control. The soil organic component that was present frequently supported high activity. As compared to other Northern Rocky Mountain ecosystems we have studied, this site can be considered low in soil organic matter, particularly decayed soil wood.

As a result, we would generally recommend upgrading the organic matter resource on sites like these by leaving modest volumes of woody residue scattered over the soil surface and by using site preparation measures that minimize loss of soil organic materials.

SECOND RESPONSES

The response of trees, understory vegetation, and wildlife to different treatments is summarized and projected in this section. The analyses are based primarily on observations during the first 5 years after treatment (with some up to 9 years) and projections of those observations. Longer term analyses are discussed in the next section on use opportunities.

Regeneration and Growth of Conifers

Wyman C. Schmidt

In the seeded and planted areas, a sample of 7 to 10 percent of the population was randomly selected for measurement of survival and height development. Trees were measured in the fall of 1973, summer and fall of 1974, fall of 1975, fall of 1977, and planted trees again in the summer of 1981.

To evaluate natural regeneration, 16- to 20-milacre plots were randomly located in each unit. Seedlings were counted to give an estimate of seedling distribution (percent milacre stocking) and seedling density. In addition, cover classes of forbs, grasses and sedges, shrubs, and dead material were estimated in 1975. In 1977, biomass was measured for each of the above categories of vegetation.

PLANTING

Planted seedlings survived very well on the areas that had been dozer-piled and burned (scarified), and those broadcast burned, exceeding 95 percent at 3 years, 87 percent at 5 years, and 80 percent at 9 years (fig. 12). Meanwhile, their counterparts in the residue-removed and chip-spread treatments fared poorly. Although the planted seedlings in the residue-removed treatment were surviving at the rate of over 90 percent at 3 years, they declined rapidly to 59 percent at 5 years and 52 percent at 9 years. Planted seedlings in the chip-spread treatment declined in a similar fashion, dropping from 84 percent survival at 3 years to 49 percent at 5 years, and to 44 percent at 9 years. The survival curves for the last 4 years are essentially parallel for all treatments—the first 5 years accounted for most of the treatment effects.

Pocket gophers and other small mammals were responsible for at least one-third of the seedling mortality on all treatments during the 5- to 9-year age period. Small mammals probably accounted for an even higher proportion, but because of the time lag between measurements not all mortality could be positively identified.

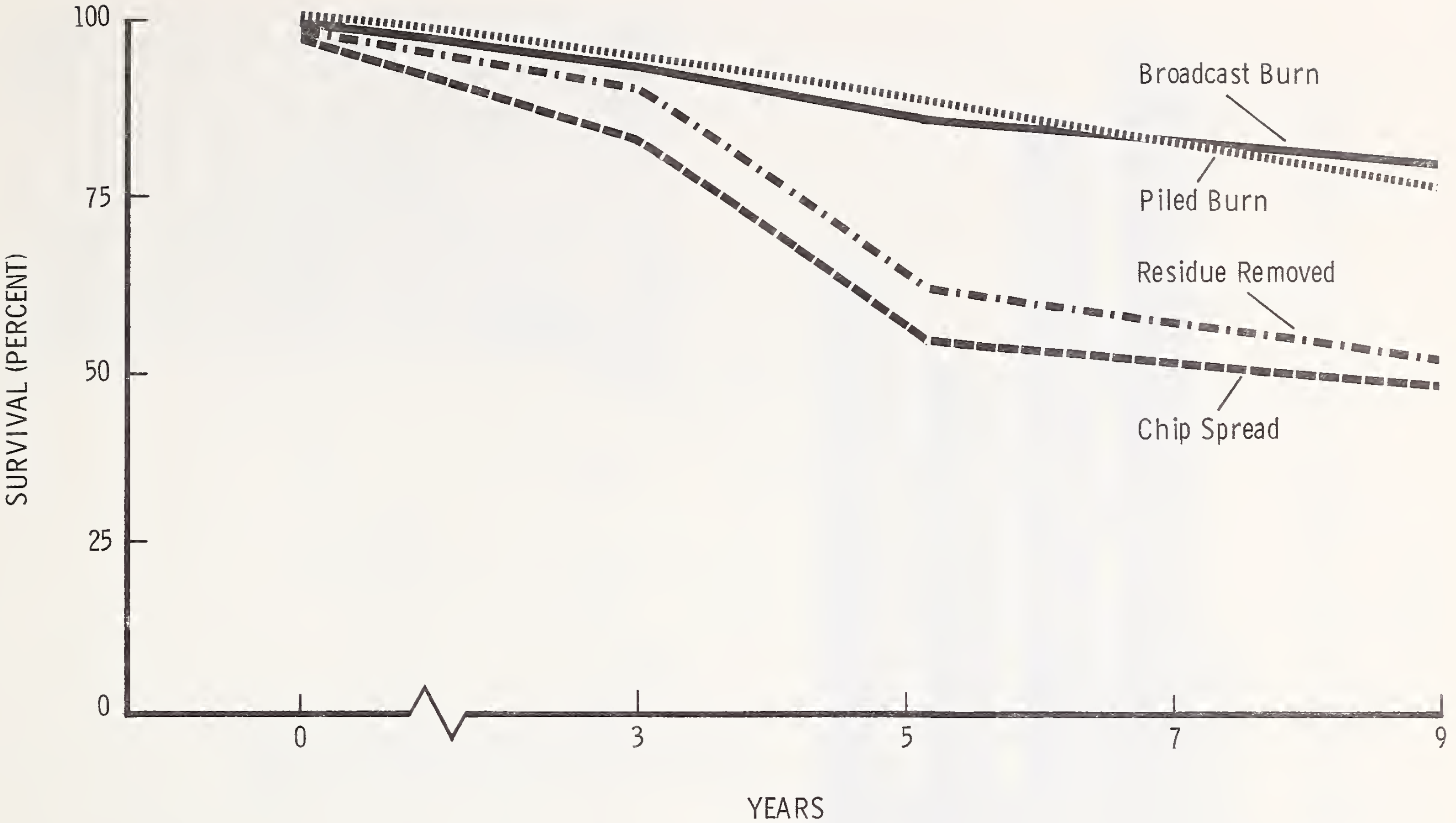


Figure 12.—Survival of auger-planted 2-0 lodgepole pine seedlings under different residues-management methods.

As shown in the following tabulation, declines in survival from age 3 to 5 were partially forecast by the percentage of seedlings with poor vigor at 3 years:

Treatment	Percent of poor vigor trees at age 3	Percent mortality between ages 3 and 5
Pile/burn (scarified)	11	8
Broadcast burn	10	8
Residue-removed	46	22
Chip-spread	40	35

Most of the trees rated poor vigor at age 3 had died by age 5. Although this was a subjective vigor rating based on overall seedling appearance, it forecast the survival rather well for the next 2 years. Comparable vigor ratings were not made at age 5.

In addition to surviving at different rates, planted seedlings grew most on the pile/burn (scarify) and broadcast-burn areas and least on the residue-removed and chip-spread areas (fig. 13). As shown, differences in height were already apparent at age 3, more pronounced at age 5, but beginning to show some amelioration of treatment differences by age 9.

Annual height growth from age 5 to 9 about doubled that noted in the 3- to 5-year period on all treatments, as shown in the following tabulation:

Treatment	Annual height increment Age 3-5		Age 5-9	
	cm	*Inch*	*cm*	*Inch*
Pile/burn (scarified)	8	3	12	5
Broadcast burn	7	3	11	4
Residue-removed	3	1	8	3
Chip-spread	5	2	11	4

Even though height growth differences on three of the treatments appeared to be ameliorating by age 9, growth on the residues-removed treatment was still lagging substantially behind the other treatments.

DeByle (1980) found the weights of typical planted lodgepole pine to vary by treatment (fig. 14). Five years after planting, the chip-spread treatment had the smallest trees (16 g), and the pile/burn (scarify) treatment yielded the largest (49 g). In comparison, seedlings from the spot-seeded sites were much smaller, ranging from approximately 2 g on the chip-spread treatment to 18 g on the pile/burn treatment 5 years after seeding.

The percentage of ash and most nutrients in the planted lodgepole pine were not statistically different among treatments (DeByle 1980). Iron is an exception. New needles of pine planted on the residue-removed units had a much lower iron concentration than did new needles on seedlings from the other three treatments. In contrast, the iron content of roots from residue-removed units was more than twice that found in roots from the other treatments. Based upon both a literature review and field observation, there were no apparent nutrient deficiencies in either the seeded or planted lodgepole pine on

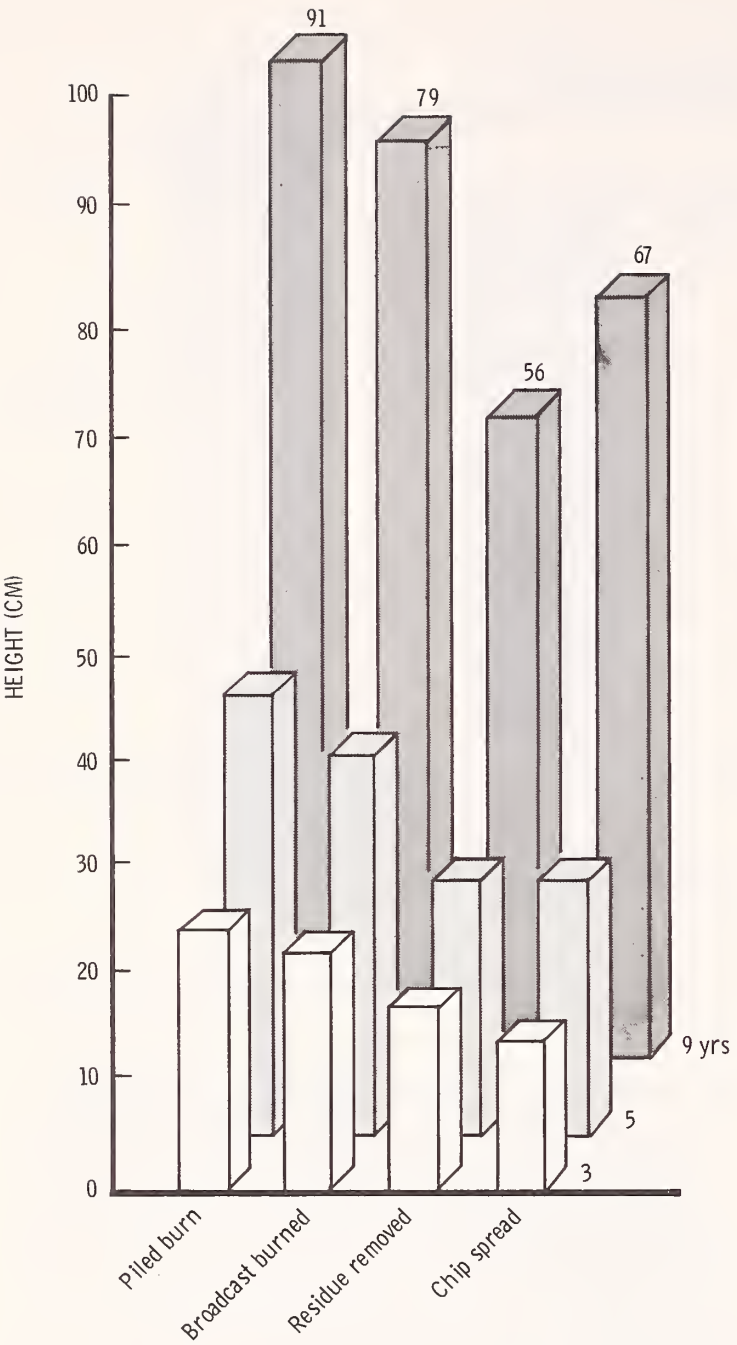


Figure 13.—Height development of auger-planted 2-0 lodgepole pine seedlings under different residues-management methods.

these sites. The markedly different growth rates of trees growing on the four treatments appear to be caused by something other than nutrient availability (DeByle 1980). Possible explanations are examined in a later section, "Factors Affecting Regeneration."

SPOT SEEDING

Broadcast burning and scarification accomplished by piling the slash created conditions most favorable for the establishment of lodgepole pine by spot seeding (fig. 15). Stocking rates for spot seeding on the broadcast-burn and pile-burn treatments were about double those of the residue-removed and chip-spread treatments. Even at that, none of the treatments resulted in stocking rates that exceeded 50 percent 5 years after seeding.

Percentage of stocked plots declined during the period 1 to 5 years in all of the treatments, but stocking on the broadcast-burn and pile/burn treatments appeared to be leveling off. Meanwhile, those in the residue-removed treatment continued a steady decline throughout the 5-year period, and those in the chip-spread dropped substantially between years 1 and 3, but declined at a slower rate in years 3 to 5 than previously.

Residue treatments influenced the first 5 years' height growth of the spot-seeded seedlings in much the same manner as they did the stocking rates. Height growth was twice as great on the broadcast-burn and pile/burn areas as on the residue-removed and chip-spread treatments, based on the tallest seedling in each seed spot (fig. 16). These differences were already significant at 3 years and even more pronounced at 5 years.

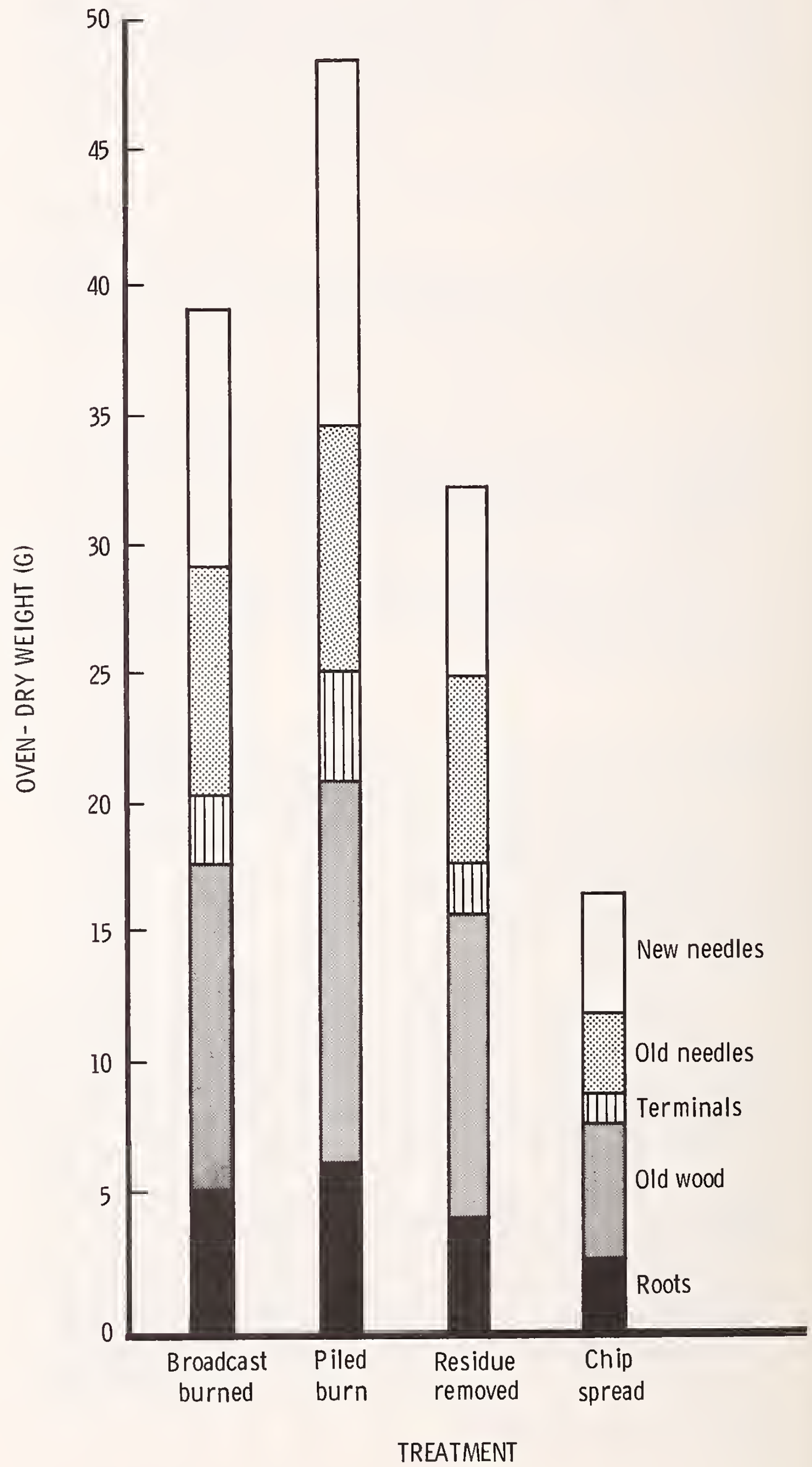


Figure 14.—Weights, by component, of typical lodgepole pine 5 years after planting on each treatment.

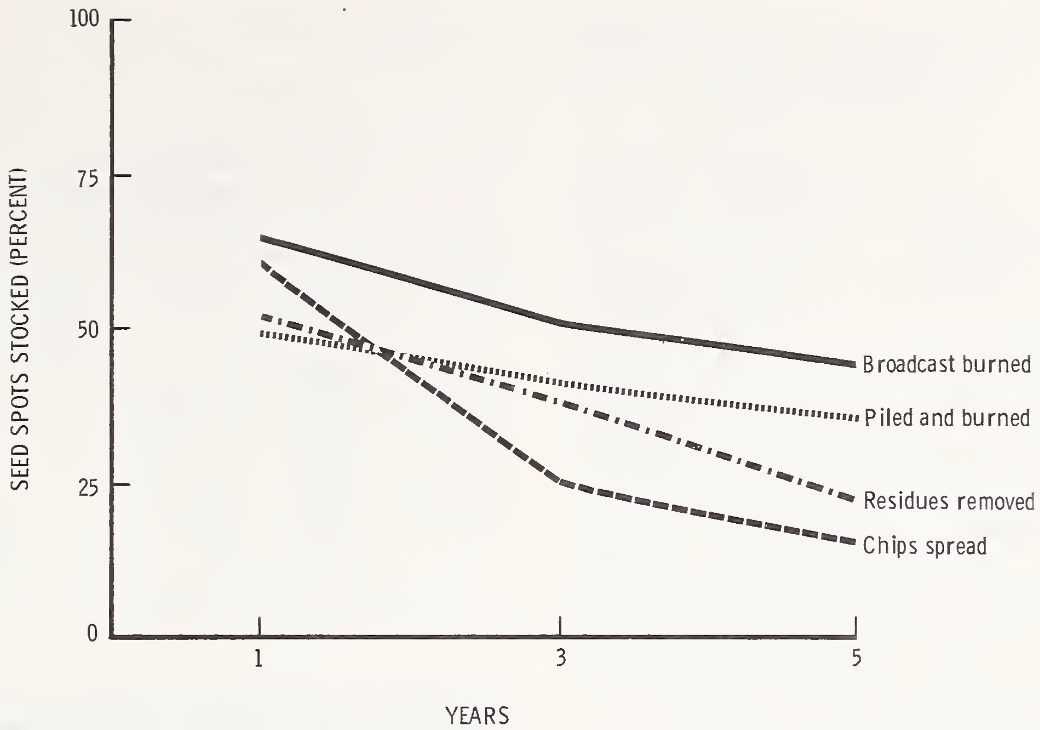


Figure 15.—Percent of seed spots stocked with lodgepole pine seedlings under different residues-management methods.

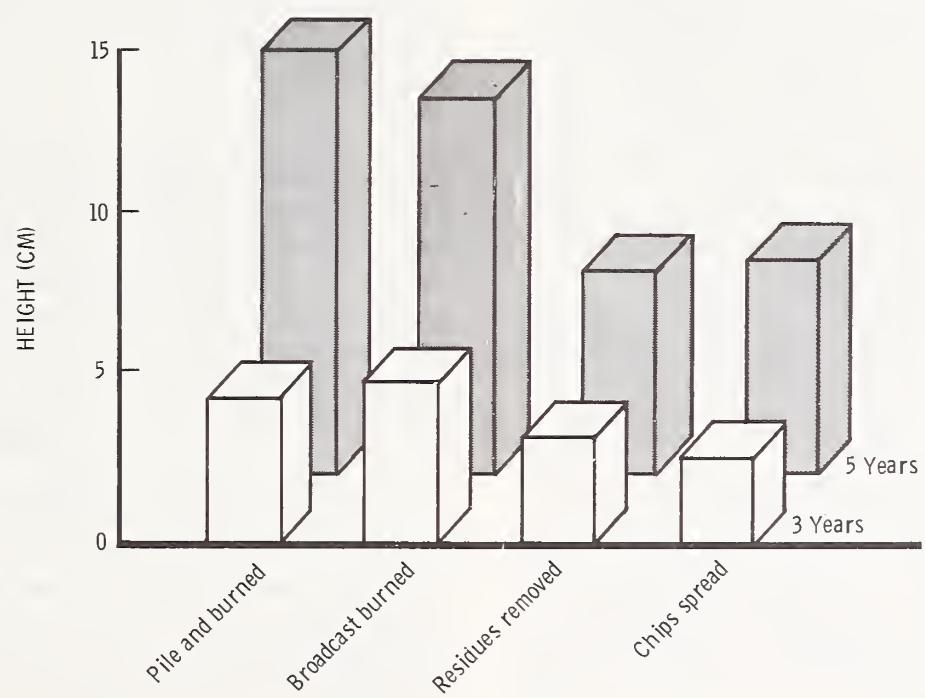


Figure 16—Average height of the tallest seedling per seed spot by residues treatment and year.

Table 13.—Natural regeneration of lodgepole pine at 3 and 5 years under different residues management methods

Treatment	Years after treatment	Milacre stocking	Seedling density		Height of dominant seedlings 5 years after treatment	
		Percent	*Per acre*	*Per ha*	*Inches*	*cm*
Pile/burn (scarified)	3	56	2,220	5 483	—	—
	5	66	2,630	6 496	7.5	19.0
Broadcast burn	3	11	130	321	—	—
	5	20	300	741	2.0	5.1
Residue-removed	3	50	1,890	4 668	—	—
	5	35	1,200	2 964	5.0	12.7
Chip-spread	3	3	30	74	—	—
	5	9	230	568	1.6	4.1

NATURAL REGENERATION

Natural regeneration was more than adequate on the pile/burn treatment, averaging about 2,630 trees per acre (6 500 per hectare), with a 66 percent stocking rate (table 13). At age 5, the area was stocked with nearly 1,200 trees per acre (3 000 per hectare), with a 35 percent milacre stocking rate. However, both stocking rate and seedling density were less than adequate on two other treatments. A good estimate for the broadcast-burn treatment is not possible because a good seed fall occurred in 1971 immediately following logging, but before burning in the spring of 1973. Nearly all of the seedlings that germinated in 1972 were probably consumed in the fire. Poor seed production in subsequent years left the broadcast burn with few seedlings, even after 5 years.

Very little natural regeneration was evident at 3 years on the broadcast-burn and chip-spread treatments, and even by age 5 only a few poorly distributed seedlings were established (table 13). This poor showing, however, was attributed to having burned up the 1972 seedlings rather than due to the treatment per se. Natural regeneration was fairly successful on the residue-removed treatment at age 3, but both stocking rate and seedling density declined in the following 2 years.

Average seedling heights were closely related to the number and stocking of seedlings established on the different treatments—those with the greatest stocking also produced the tallest average trees. Some of the differences in height were likely a function of seedling age. For example, nearly all of the seedlings now found in the broadcast burn were established about 3 years after those in the pile/burn treatment.

FACTORS AFFECTING REGENERATION

The survival and growth data above indicate that the method used to dispose of wood residues following clearcutting in lodgepole pine forests clearly affects subsequent regeneration. This holds true for both survival and initial development of both artificial and natural lodgepole pine regeneration. Differential effects of the residue treatments are pronounced after 5 years and measurements at 9 years of the planted seedlings indicate treatment differences still persist. The general trend hints that some of the differences will continue—how long can only be speculated at this time. Studies with western larch (*Larix occidentalis*) under somewhat similar circumstances showed seedbed treatments affecting seedling and sapling development for 15 to 20 years (Schmidt 1969; Schmidt and others 1976).

The more conventional methods of seedbed preparation in lodgepole pine forests resulted in the best survival and seedling development in this study. Both dozer piling and burning, and broadcast burning are used extensively in lodgepole pine forests for seedbed preparation. Results from this study provide additional support for those methods as far as seedling establishment and development are concerned. This held true for all three types of regeneration practices—planting, spot seeding, and natural.

For the first 5 years, the residue-removed and chip-spread treatments had poor regeneration, and their long-term trend is not favorable. For example, planted tree survival and growth on these treatments is substantially less than on the two conventional treatments, and the trends are persistent. The same relationship holds true for spot seeding, and, to a lesser extent, for natural regeneration. The natural regeneration picture for the broadcast burning is clouded because of the delayed burning and subsequent loss of first-year seedlings. Other studies have indicated that natural regeneration on pile/burn and broadcast-burn areas is essentially the same, but with somewhat fewer seedlings surviving in the burned seedbeds (Alexander 1966).

Many individual factors or combinations thereof probably contribute to differences in seedling response. One possibility is the difference in soil temperatures reported in the previous section. Soil temperatures under the chip-spread treatment ranged from 5° to 20° cooler than some of those in the open (Hungerford 1980). As described by Lotan and Perry (1976), cool soil temperatures can inhibit plant-water uptake, retard nutrient release and absorption, and slow terminal leader growth of plants, perhaps by inhibiting hormone transfers from root to top. Differences in net radiation could also be involved, but at this time the implications of net radiation are not fully understood.

Nutrients are often felt to be a major cause of differential tree response on areas treated with some of the residue disposal methods used in this study. Broadcast burning increased levels of potassium, calcium, magnesium, and nitrates (DeByle 1980) and may have contributed to the superior growth of the regeneration that developed as a result of seeding. But planted seedlings did not similarly respond—probably because the flush of available nutrients essentially disappeared the second season, before the

seedlings developed a root system capable of capitalizing on the nutrients.

Concentrations of nutrients in the planted seedlings growing on the different seedbeds gave no ready explanation for growth differences. As indicated previously, major nutrients were similar in the different lodgepole pine seedling components in the different treatments. However, the evaluation of true nutrient availability and disposition is difficult because on more favorable treatments seedlings grew larger, and nutrients therefore may appear to be less concentrated.

Interestingly, the two treatments with the least tree response also were the treatments with the greatest percentage of organic matter in the upper 2 in (5 cm). Much of the nitrogen in this strata may have been "tied up" in the decomposition process and as a result unavailable to the seedlings even though present. Compaction did not appear to adversely affect initial establishment and development here. Data reported earlier indicate the most compaction (as measured by bulk density) occurred on the scarified areas—the areas that produced the best seedling response.

A flush of phenols in 1973, the first year seedlings were planted and seeded, may have played an active role in retarding seedling establishment and subsequent growth. If so, the high contents of phenols—658 parts per billion in the chip-spread and 320 parts per billion in the residue-removed treatments—had a long-term compounding effect because phenol levels had returned to normal by 1974 (Hart and DeByle 1975). Plant tissue commonly contains phenols (Bate-Smith 1962) with high concentrations in dead and dying woody plants (Jorgenson 1961; DeGroot 1966). Phenols are credited with both stimulating (Michniewicz and Galoch 1974) and inhibiting (Mensah 1972; Demos and others 1975) plant growth.

Interestingly, high phenol levels on the chip-spread and residue-removed treatments were associated with organic matter levels in the top 2 in (5 cm) of the soil. As described earlier, organic matter accounted for 11 to 12 percent of the upper soil layer in the residue-removed and chip-spread treatments in 1975 as compared to 4 to 6 percent in the other treatments. The increased organic matter in the upper soil of the residue-removed treatment was believed due to the incorporation of fine residues, such as pine needles, into the upper soil during the intense removal of all the larger residues.

Projections of Timber Stand Development

Dennis M. Cole

The previous section covered tree survival and early growth of lodgepole pine regeneration on the different residue treatment areas. These data were the basis for computer projections of stand development with a revised version of "LPMIST" (Myers and others 1972). The projections provide a comparison of treatments at different future ages by such characteristics as expected volume, increment, and tree size. The projection model used is designed to make decadal projections, beginning at age 20, of several key parameters of stand growth and yield—average stand diameter by basal area, mean height of dominant trees, and stocking in trees per acre—as a function of site index, elevation, and initial values of average stand diameter, mean height of dominants, and trees per acre.

Measurement data were only available at 3, 5, and 9 years for planted regeneration, and for only 3 and 5 years for direct-seeded and natural regeneration. Twenty-year values for starting the projections were derived for two assumed stand development scenarios that are plausible alternatives for stand development, from 5 to 20 years following stand regeneration. The first alternative assumes essentially no further seedling mortality from the last measurement to year 20. The second alternative assumes that noncatastrophic mortality under all methods of regeneration will continue during the period 5 to 20 years, at an average rate of 1.5 percent per year. This rate was observed for planted seedlings in the period from 5 to 9 years following planting. Which of the two assumptions is more applicable for each of the regeneration methods—or whether an intermediate rate of mortality between the two assumed is involved—can only be determined by future remeasurements of the study plots. In the interim, however, we believe that by keeping our assumptions clearly in mind, we can tentatively gain some idea of the magnitude of long-term effects of the residue treatments by projecting stand development under these two different, yet plausible, courses of early survival and growth. Unforeseen events such as wildfire, insect or disease epidemics, and additional (excessive) natural regeneration can alter the future stand; however, these factors are not built into our projections.

The 12 residue-treatment/regeneration-method combinations of the study were projected by 10-year growth intervals under each of the above-mentioned assumptions to 150 years. Projected volumes, mean annual increments, and ages at increment culmination are shown for total cubic volumes and board-foot volumes of each treatment (tables 14a and 14b). Also shown is the number, d.b.h., and board feet represented by the average tree at culmination of board-foot increment. Supplemental tables were developed to summarize for each treatment and assumption (at the culmination of board-foot MAI): (1) volume, stocking, and average size of green and dead standing timber; (2) volume of both green and dead residues; and (3) expected timber values (appendix tables 31-35). From the projections and the resultant summary tables, growth curves and average d.b.h.'s were developed for the maximum and minimum values of each stocking assumption to illustrate the respective ranges in which all treatment responses appear to occur (figs. 17 and 18). The principal differences among the stocking assumptions, and among treatments within a stocking assumption, appear to be:

1. *Cubic volume and growth.*—Culmination of mean annual increment occurred at from 70 to 90 years for stocking assumption 1, and from 70 to 100 years for stocking assumption 2, depending on treatment. Total volume under assumption 1 varied from 3,980 ft^3 per acre (278 m^3/ha) (broadcast burn with natural regeneration) to 5,250 ft^3 per acre (367 m^3/ha) (pile/burn with spot seeding). Under assumption 2, total volume varied from 3,270 ft^3 per acre (229 m^3/ha) (chip-spread with spot seeding) to 5,060 ft^3 per acre (354 m^3/ha) (broadcast burn with planting). Differences appear to be related to differences in trees-per-acre stocking among the treatments.

2. *Saw log volume.*—Culmination of mean annual increment on a board foot basis occurred at 90 to 130 years for stocking assumption 1, and at 110 to 130 years for assumption 2. Total volume at culmination was between 18.1 and 23.4 M bd.ft. per acre (44.7 and 57.8 M bd.ft./ha) for both stocking assumptions, except on direct seeding after piling and burning, under assumption 1, where volume was 16.6 M bd.ft per acre (41.0 M bd.ft./ha).

3. *Tree stocking and size.*—There is a notable difference between stocking assumptions and among treatments as to the

Table 14a.—Projected volume, mean annual increment, and tree size, by treatment (assumes no substantial mortality between ages 5 and 20)

Treatment	Total cubic volume all trees to tip			Saw log volume - bd.ft. of trees 6.5 in d.b.h. to 6.0 in top					
	Culmination of cubic foot MAI		Total volume at culmination of MAI	Culmination of bd.ft. MAI		Total volume at culmination of MAI	Average tree at culmination of bd.ft. MAI		
	Age	MAI		Age	MAI		No./ acre	Average d.b.h.	Volume of average tree
	Yrs	*Ft³/yr*	*Ft³/acre*	*Yrs*	*Bd.ft./yr*	*M bd.ft./acre*		*Inch*	*Bd.ft.*
Pile and burn (PB)									
Planted (P)	90	56.8	5,110	100	187	18.7	400	9.1	47
Seeded (S)	90	58.4	5,250	90	184	16.6	458	8.5	36
Natural (N)	70	60.8	4,250	130	146	19.0	675	7.4	28
Broadcast burn (BB)									
Planted (P)	90	56.8	5,110	100	187	18.7	400	9.1	47
Seeded (S)	90	56.8	5,110	100	187	18.7	400	9.1	47
Natural (N)	80	49.8	3,980	120	193	23.1	198	12.1	117
Chip-spread (CS)									
Planted (P)	90	51.8	4,060	120	194	23.3	225	11.6	104
Seeded (S)	90	47.7	4,290	110	191	21.0	176	12.4	119
Natural (N)	90	47.6	4,280	120	192	22.9	157	13.1	146
Residue-removed (RR)									
Planted (P)	90	53.3	4,790	120	195	23.4	249	11.2	94
Seeded (S)	90	56.8	5,110	100	187	18.7	400	9.1	47
Natural (N)	80	58.3	4,660	110	165	18.1	532	8.1	34

Source: Projections by D. M. Cole, Intermountain Forest and Range Experiment Station, Bozeman, Mont.

Table 14b.—Projected volume, mean annual increment, and tree size, by treatment (assumes 1.5 percent annual mortality between ages 5 and 20)

Treatment	Total cubic volume all trees to tip			Saw log volume - bd.ft. of trees 6.5 in d.b.h. to 6.0 in top					
	Culmination of cubic foot MAI		Total volume at culmination of MAI	Culmination of bd.ft. MAI		Total volume at culmination of MAI	Average tree at culmination of bd.ft. MAI		
	Age	MAI		Age	MAI		No./ acre	Average d.b.h.	Volume of average tree
	Yrs	*Ft³/yr*	*Ft³/acre*	*Yrs*	*Bd.ft./yr*	*M bd.ft./acre*		*Inch*	*Bd.ft.*
Pile and burn (PB)									
Planted (P)	80	55.6	4,440	110	196	21.6	297	10.4	73
Seeded (S)	80	50.7	4,050	120	193	23.2	208	11.9	112
Natural (N)	70	58.8	4,110	130	148	19.3	614	7.7	31
Broadcast burn (BB)									
Planted (P)	90	56.3	5,060	110	196	21.6	313	10.2	69
Seeded (S)	90	53.3	4,950	120	195	23.4	249	11.2	94
Natural (N)	90	48.6	4,370	110	194	21.3	176	12.4	121
Chip-spread (CS)									
Planted (P)	80	49.4	3,950	110	192	21.1	194	12.0	109
Seeded (S)	80	40.9	3,270	110	186	20.5	107	14.6	192
Natural (N)	100	44.8	4,470	110	192	21.1	137	13.5	154
Residue-removed (RR)									
Planted (P)	80	49.8	3,980	120	192	23.1	198	12.1	117
Seeded (S)	100	46.3	4,120	110	195	21.4	151	13.1	142
Natural (N)	80	59.7	4,770	110	170	18.7	505	8.3	37

Source: Projections by D. M. Cole, Intermountain Forest and Range Experiment Station, Bozeman, Mont.

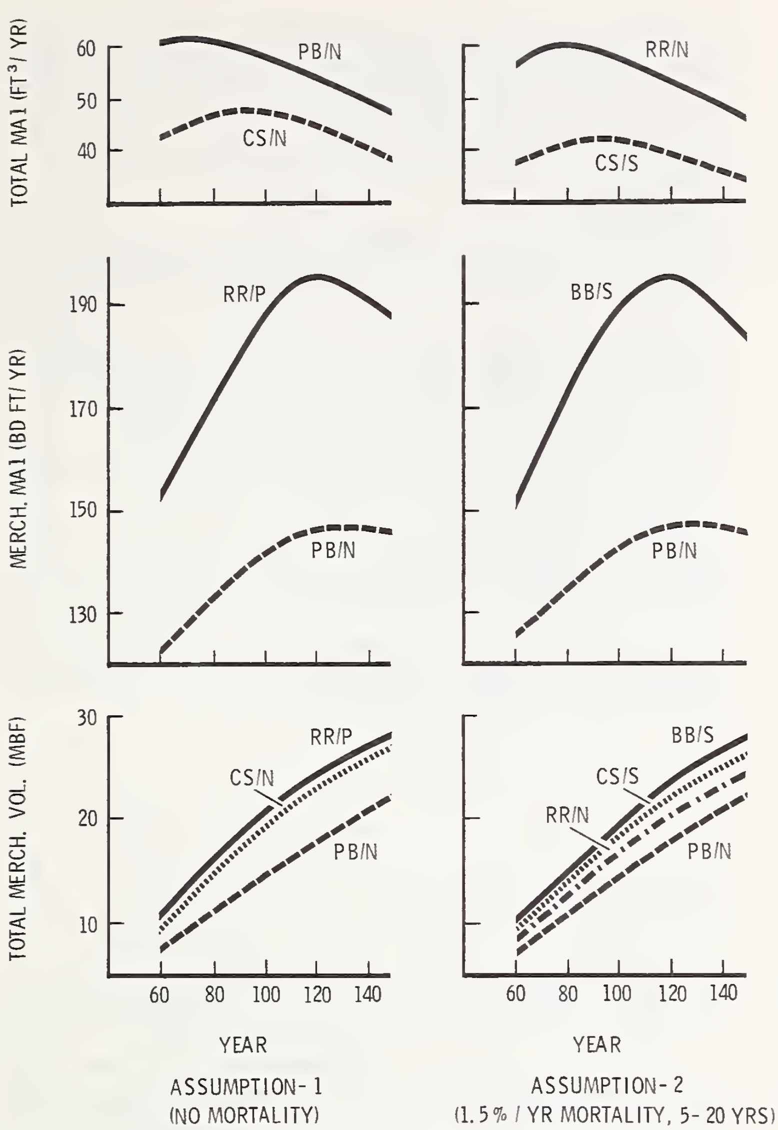


Figure 17.—Growth and volume projection—selected treatments.

nature of the stands. Under assumption 1, stocking at culmination of board-foot MAI is seen to vary on 7 of the 12 treatments from 675 to 400 trees per acre (1 667 to 988/ha), averaging 7.4 to 9.1 in (18.8 to 23.1 cm) d.b.h. The other five treatments are notably different. On the chip-spread (all regeneration methods), the broadcast burn with natural regeneration, and the residue-removed with planting, stocking varied from about 160 to 250 trees per acre (395 to 617/ha), with diameters averaging from 13.1 to 11.2 in (33.3 to 28.4 cm). In contrast, at culmination of board-foot MAI under assumption 2, only the pile/burn with natural regeneration (614 trees/acre; 1 517/ha), the residue-removed with natural regeneration (505 trees/acre; 1 247/ha), the broadcast burn with planting (313 trees/acre; 773/ha), and the pile/burn with planting (297 trees/acre; 733/ha), exceeded 250 trees per acre (617/ha). The average d.b.h. of these treatments ranged from 7.7 in (19.5 cm) with 614 trees per acre (1 517/ha), to 10.4 in (26.4 cm) with 297 trees per acre (733/ha). The remaining eight treatments under assumption 2 showed stocking levels between 107 and 249 trees per acre (264 to 610/ha), with corresponding diameters in the respective range of 14.6 to 11.2 in (37.1 to 28.4 cm).

In summary, although neither cubic-foot nor board-foot volumes were greatly influenced by the different stocking assumptions, tree sizes and value considerations were considerably affected. Differences in tree size among treatments, within stocking assumptions, were also noted and discussed in the preceding paragraph. Additional insight on these effects can be gained by examining supplementary tables 31-35 of the appendix, where ramifications of tree size and value are expressed in additional ways that are important for assessing tradeoffs in resource values.

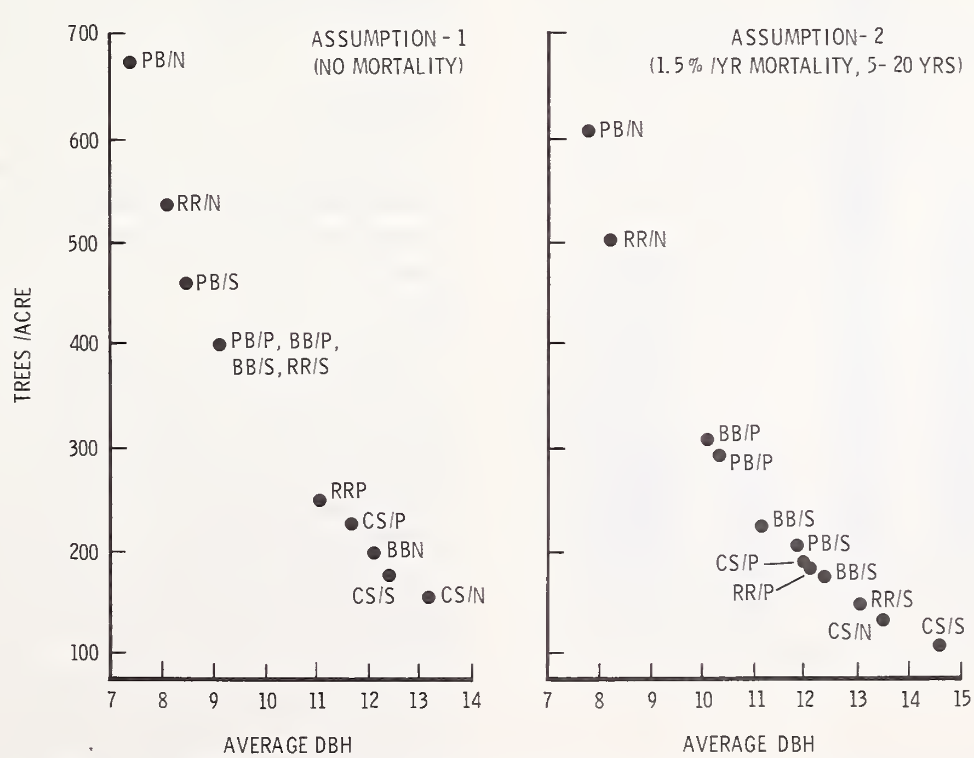


Figure 18.—Average d.b.h. and stocking of dominant and codominant trees at culmination of board foot mean annual increment.

Regrowth of Understory Vegetation

Wyman C. Schmidt

Vegetative cover was measured 3 years after treatment and averaged 11 percent forbs and 2 percent grasses and sedges on the scarified and broadcast-burn treatments; and 20 percent forbs and 9 percent grasses and sedges on the residue-removed treatment. There was practically no vegetative cover on the chip-spread treatment.

The biomass of vegetative components varied substantially. As shown in figure 19, understory vegetation was sparse in the uncut mature forests in the study area. With the exception of the chip-spread treatment, all of the treatments produced more vegetation than the uncut forest. Forbs accounted for about a third of the understory biomass in the uncut forest, but they predominated on the treated areas. For example, in the burned-treatment area, forbs accounted for over three-fourths of the biomass. On the other hand, shrubs accounted for a third of the biomass in the uncut forest and were practically nonexistent on the treated areas. Grasses were practically nonexistent in the uncut forest and the chip-spread treatment, but accounted for over a third of the biomass in the pile/burn and residue-removed treatments.

Vegetative competition commonly inhibits seedling survival and development. With the possible exception of the residue-removed treatment, however, vegetative competition does not appear to be significant in this case. The relatively low levels of vegetation measured as live biomass on the entire area casts doubt on its role as a strong competitor. The grass component would likely be the primary competitor, but the amounts of grass on the pile/burn treatment (which produced the best tree growth) was essentially the same as on the residue-removed treatment (which had poor tree growth).

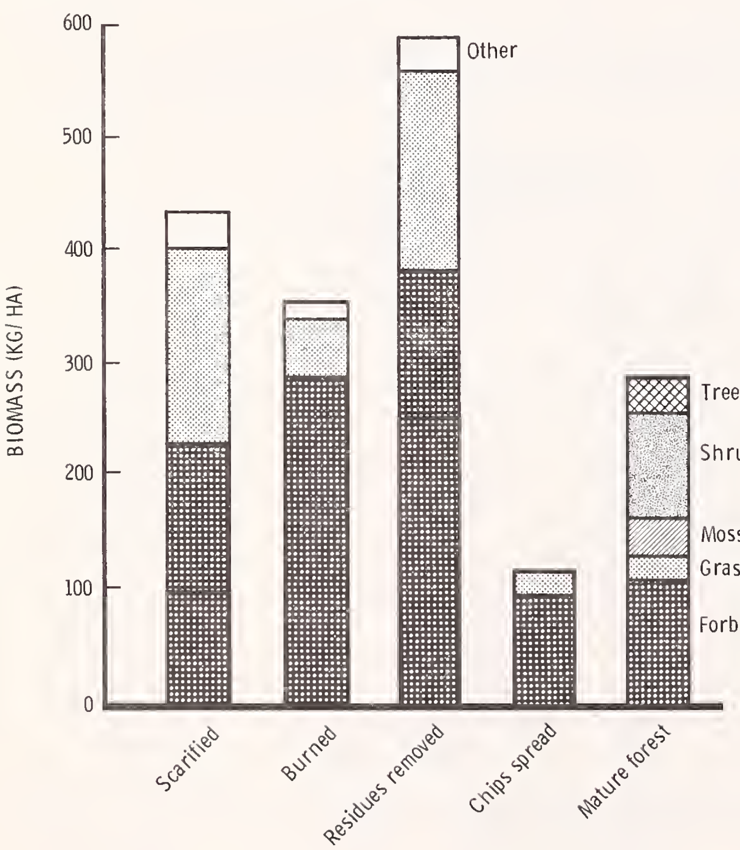


Figure 19.—Biomass of the understory vegetation 5 years after clearcutting and subsequent residues treatments.

Understory vegetation was sampled prior to harvesting and also in connection with the infiltrometer plots. The total biomass varied slightly from that in figure 19, probably because of sampling differences and also seasonal and year-to-year differences. Nevertheless, the relative differences among treatments were about the same.

To fully assess potential effects of future treatments, growth of understory vegetation was projected to complement the tree growth projections. Past research indicates that understory vegetation typically peaks at about 12 years after harvest, and produces about 800 to 900 lb per acre (900 to 1 000 kg/ha) at the peak (Basile 1971). Projections of the data indicate the chip-spread treatment will remain low, under 100 lb per acre (110 kg/ha), but the other treatments will produce about 950 to 1,200 lb per acre (1 050 to 1 350 kg/ha) at 12 to 13 years (fig. 20). Beyond that time, as tree crowns begin to shade the understory vegetation, herbage production on most treatments will tend to equalize at about the level of the uncut forest by year 25. Vegetation will probably remain sparse on the chip-spread treatment. This is speculation because we know of no previous experience with spreading chips on forest sites.

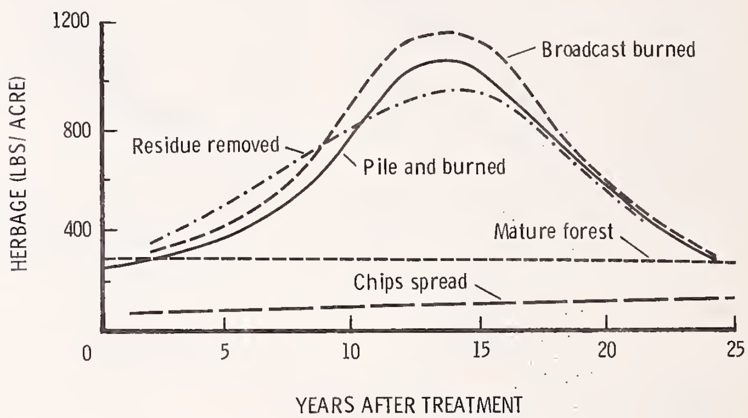


Figure 20.—Projected production of understory vegetation.

Wildlife

Joseph Basile

The scope and design of this study allowed for only limited direct evaluation in terms of wildlife. For the most part studies evaluate the effect of treatments on wildlife habitat. This section reports on the immediate effects of treatment.

EFFECTS ON WILDLIFE HABITAT

The evaluation of treatment effect on wildlife and domestic livestock is based partly on vegetation and regeneration data, but mostly on intuitive expectations derived from professional experiences of several individuals. What follows, then, is largely opinion; but, we feel, an informed opinion.

Although expectations are discussed here for the treated sites, it is unrealistic to view their effects on wildlife as entities in themselves. Except for a few species of small mammals, none of the wildlife species rely solely on habitat contained wholly within the treated site. Rather, the individual ranges of most mammals and birds will encompass parts or all of several units within the area. Most species will fare best where those units present a variety of stages of vegetation development and complexity. The "edges" between uncut forest and cut blocks, and between cut

blocks of widely differing ages, are especially important, particularly to some of the larger animals that require a taller protective screening than that provided by early seral stages.

All treatments, except the chip-spread, produced within 5 years understory vegetation superior to that of the uncut forest both in amount and in species diversity. Cover, however, which is also essential to most wildlife species, is in part tied to residues left on the site and conifer regeneration and growth, as discussed in the following treatment assessments made about 5 years after harvest.

Chip-spread.—This treatment is undesirable for wildlife. Herbaceous vegetation is expected to be unacceptably low, both in species diversity and in total production, for two or more decades. Natural regeneration of lodgepole pine is highly unlikely. The performance of direct-seeded and planted stock 5 years after planting indicates poor survival and growth rates. Thus, both food and cover for small and large mammals and for birds are expected to be lacking for at least 20 years, and possibly much more.

Residue-removed.—This treatment is the least disruptive to the soil and the understory vegetation. Consequently, more biomass is expected here than on other treatments for the first few years after logging. With the relative absence of scarification and with no burning, however (both of which promote herbage production), less biomass is expected here for about two decades than on the broadcast or pile/burn treatments. Relatively poor performance of tree regeneration, coupled with the absence of logging debris, renders the residue-removed treatment units devoid of significant hiding cover for most mammals and of perching opportunity for birds. As herbaceous vegetation cover increases, the area should become more attractive to small rodents and, in turn, to raptors.

The removal of all snags, limbs, and other logging debris eliminates the impediment to livestock and big-game travel often imposed by debris on conventionally logged areas.

The net long-term effect of this treatment is beneficial to wildlife and to livestock. Herbaceous production should equal or exceed that of the uncut forest within 3 or 4 years after logging, and should continue to increase until peaking at about 15 to 20 years. Cover should be adequate for most small mammals within 5 years, and for larger mammals (deer, elk) in 20 to 25 years.

Broadcast burn.—This treatment is perhaps the most beneficial to wildlife, in that it combines a high forage production with good escape cover within a relatively short time. Survival and growth rates of lodgepole pine 5 years after planting were higher than on the residue-removed units, giving rise to expectations of a somewhat faster attainment of good cover conditions for large mammals here than on the complete removal units. Production of herbaceous vegetation will exceed that of the uncut forest in 3 to 5 years, and should peak in 10 to 15 years at a level above that of the residue-removed areas.

Unburned logging debris is usually sufficient to provide immediate cover for small mammals and roosts for passerine birds. At the same time, the debris is not concentrated enough to seriously impede travel by big game or livestock. The suitability of the habitat for small mammals enhances its attractiveness for raptors and carnivores.

Pile/burn.—This treatment will generally yield less herbaceous vegetation, and at a slower rate than the broadcast-burn treatment. This is partly because soil is displaced in piling, and partly because soil is temporarily sterilized by extremely hot, prolonged fire in concentrated slash piles. Nonetheless, the biomass should peak in approximately 15 years at a level above that of the residue-removed unit.

Cover for small rodents and perches for songbirds are generally abundant, and so in turn it is favorable to raptors and carnivores. Unburned log piles are conducive to good marmot habitat. Unburned debris on pile/burn sites, however, particularly when the slash is windrowed, may hinder elk travel and discourage use.

Stocking, survival, and growth rates of planted lodgepole pine can be expected to be very good on pile/burn sites. The screening effect of young trees, coupled with that of the slash piles, combine to rather rapidly provide a protective cover for the larger mammals as well as the rodents.

To summarize the four treatments, then, we may expect herbaceous vegetation to respond similarly to all but the chip-spread treatment; that is, a rapid rise in production, peaking at about 10 to 15 years at not widely divergent levels.

The protective cover afforded wildlife differs more with treatment than does herbage production. Ample cover and perches provided by logging debris remaining after broadcast or pile/burn treatments render these areas immediately more suitable for small mammals and birds, and thus to carnivores and raptors, than are areas from which all residues are removed. These differences in cover values are further magnified by the higher survival and growth rates of lodgepole pine stock on the conventionally treated areas.

OBSERVATIONS OF WILDLIFE

The following wildlife were observed one year after the harvest:

Old-growth, uncut.—Juncos, chickadees, nutcrackers, and various woodpeckers were common. Red squirrels and chipmunks were common; few pocket gophers.

Older clearcuts in area.—Twenty-three species of birds, including open meadow species. Droppings from hare, porcupine, bear, coyote, moose, elk, and deer.

Study units, first year.—Birds limited to edge of cutting units. Pocket gophers emigrated about 1 chain into unit during the first winter but population was low.

In subsequent years, researchers at the site have made casual observations of wildlife. Elk and moose use the areas each year even though it has been fenced to exclude livestock. Moose have destroyed portions of the fences. Small birds are seen in the areas, although more so in the burned units where logs provide perches. There does not appear to be as many varieties or numbers of birds in the study units as in older clearcut units. In general, wildlife response appears to be as expected by wildlife biologists when they initially viewed the treatments.

Rodents are of particular concern in areas to be regenerated because they eat seeds and gnaw on roots or stems of seedlings. As noted earlier, rodent poison was distributed the year the area was regenerated. No population estimates were made prior to

harvest, but in subsequent years some snap trapping was done in the area.[3] This was not a rigorously designed study and it is not possible to derive estimates of rodent population density from the data. The following tabulation indicates that the population may be much reduced where residues were removed. Unfortunately no data were taken in the chip-spread treatment.

Treatment	Percent of trap sets[1] that were "hits" (animal caught or trap sprung)
Uncut timber	30
Broadcast burn	26
Pile/burn	21
Residue-removed	16

[1]Using χ^2 test, hit rate in uncut timber and broadcast burn is significantly different from hit rate in pile/burn and residue-removed (at the 0.95 level of probability).

These trapping data tend to substantiate predictions of wildlife habitat for different treatments. Little evidence has been noted of rodents in the chip-spread treatment.

The evaluations of treatment effects on wildlife are based primarily on the differences in herbaceous cover. The importance of these cover differences diminishes with time and with proximity to edges of older cuts and uncut forest. Thus, effects of treatments on wildlife are best understood when the working circle, with its mosaic of cuts of various ages, sizes, and shapes, is viewed in its entirety. For comparative purposes, however, the changes in forage and cover are used directly as indicators of differences in the effect of treatments on wildlife, and are analyzed further in the next section on use opportunities.

EFFECTS ON USE OPPORTUNITIES

The preceding sections have described the physical and biological responses to various harvesting and regeneration treatments. For this information to be useful for management, it was necessary to project the future development of trees and lesser vegetation and interpret the responses in terms of the resources the manager works with. To translate observations made on these specific harvesting sites into a broader analysis, it was necessary to make two additional assumptions:

Spatial aspects.—Our assessment is primarily tied to the harvest unit. Most of the wildlife and some of the vegetation responses are not limited to the onsite harvest unit effects. The arrangement and extent of cutting units and related spatial aspects such as proximity to streams and roads are beyond the scope of this analysis. For example, the effect of one cutting unit in isolation will be different than the effect of 10 units in close proximity along a road. We do not address these aspects here.

Measures of response and use opportunities.—Ideally all impacts and responses would be measured by a common scale such as dollars. Nevertheless, not all responses can be interpreted in common units. Therefore, several measures are used: dollars, quantities, or in some cases, a simple index of favorable or unfavorable responses.

[3]James E. Lotan. Data on file at FSL, Missoula, Mont. 1973.

The following sections compare and analyze the impact of treatments on several principal use values: wildlife, grazing, recreation and esthetics, soil and water, and timber.

Wildlife Values

The discussion of wildlife impacts in the preceding section focused on habitat changes plus limited data on species and population trends. The combination of early habitat effects, projections of vegetation response, and wildlife observations provides a reasonable basis for estimating wildlife responses.

In 1972 the Teton National Forest wildlife biologist evaluated the areas in terms of effects on wildlife.[4] Field sampling and observations of both wildlife and vegetation were combined into an index value for three time periods (at harvest, 20 years hence, and 100 years hence). Ratings developed for elk and birds shown in figure 21 are typical. Additional analyses for other species are summarized in the appendix.

Both burning treatments and residue-removed treatments were projected to be virtually the same in terms of forage and cover. Unharvested stands are superior to harvesting treatments in terms of cover, but over time forage is projected to increase on harvested areas and decrease on unharvested stands. Habitat for birds in piling and burning areas was superior to residue-removed areas in providing perching places and in the amount of food produced.

Although these evaluations were of necessity largely subjective, both burning and residue-removed treatments were judged to offer little immediate forage and cover for big game. The chip-spread areas were judged to offer even less in vegetation response and wildlife potential.

Interpreting these responses in terms of resource uses involves some assumptions as to what is "good" and what is "bad." For example, what is good for one wildlife species, such as pocket gophers, may be bad for timber because gophers damage roots of young trees.

The general context in which wildlife is evaluated must then be established. For each of the species or groups of species evaluated, the following assumptions were used:

Moose, elk, and deer.—Although these animals may do some damage to tree regeneration and may compete with cattle for herbage, in our assessments they are assumed to have positive value. They are commonly seen feeding in harvest units in the area, but the importance of cutting units to total food intake has not been established. Elk apparently use the study area only as transitional range enroute from lower elevation winter habitat to higher elevation summer range. Deer are not numerous in the area but seem to use the cutting units throughout the summer.

Differences among treatments in the production of herbaceous material could potentially affect big-game foraging. Because this is a transitional range and only lightly used, only a small part of what is produced is actually used. Casual observation over several years indicates that elk sedge was the primary forage, and this was utilized mostly early in the season. Small alpine fir has been closely browsed by moose, and forbs are utilized by all big game. For this reason the herbage production reported above could indicate differences between treatments in browse potential for big-game animals, but from a practical standpoint these differences will probably have little actual effect on use by elk, deer, or moose.

[4]Office report by George Gruell, June 15, 1973, on file at Intermountain Forest and Range Experiment Station, Missoula, Mont.

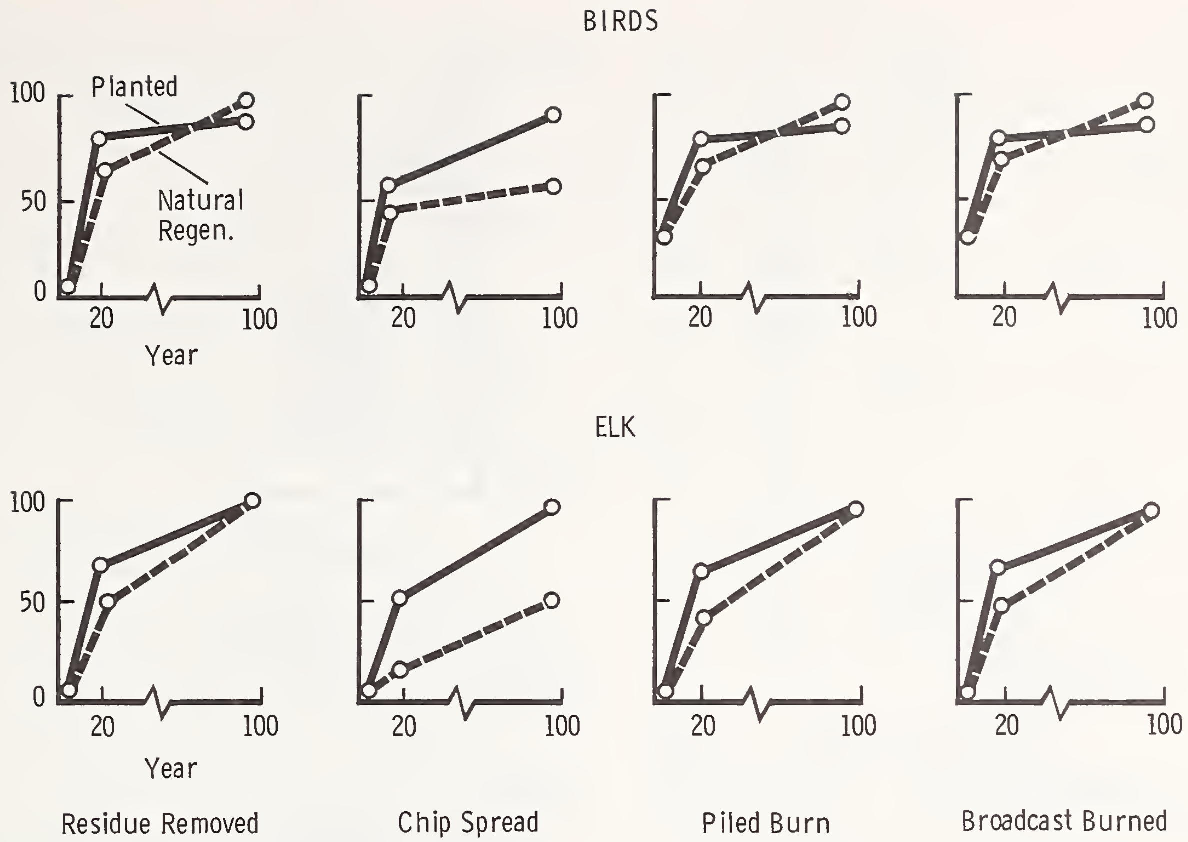


Figure 21.—Projected index of cover conditions for birds and elk, by treatment, 1, 20, and 100 years after harvest. (Source: G. Gruell, office report, Teton National Forest, June 15, 1973.)

For moose, elk, and deer there is little difference among treatments as to impact on cover. The uncut mature forest was given an index rating of 100 for cover, and initially after harvest all treatments rated 0 for big-game cover. Using projected vegetation growth 20 years after harvest when lodgepole regeneration is tall enough to provide cover, all treatments are rated 70 if planted and 50 if natural regeneration is used. The only treatment difference is in the chip-spread treatment where lodgepole regeneration would remain sparse and therefore cover rated only 10 even after 20 years.

If expected cover and forage responses are used as an index of the relative impact on the moose and elk component of wildlife, figure 22 shows the relative ranking of different treatments.

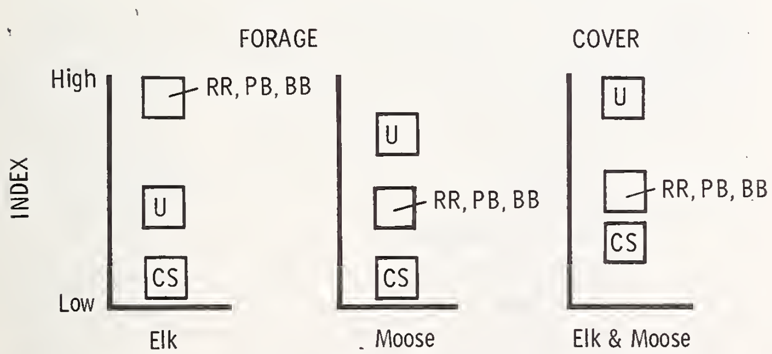


Figure 22.—Indexes of treatment effects on big game forage and cover at year 20.

As noted earlier, cover for large animals is important, but it does not respond differently among treatments. The "high-low" scale in figure 22 is not a precise measure, as are forage weights, but it provides a useful scale for the next step of analyses.

Birds.—Both small songbirds and larger birds of prey have a positive value to recreationists and for insect and rodent control. Some, such as juncos, may have a negative effect by feeding on tree seeds and newly germinated seedlings (Shearer 1976). In this analysis treatments that favor bird habitat or increase species diversity are considered positive. The preceding section reported species observed and expected trends in habitat for various treatments. An evaluation of these treatments using a 0-100 index is illustrated in figure 23.

Assuming an average value over the 20-year period gives the following annual rating for different treatments:

	Food	Cover
Pile/burn, broadcast burn	40	55
Residue-removed	30	40
Chip-spread	5	40

Because the relationship of food and cover is similar among treatments, it seems reasonable to combine both into a single composite index of bird use opportunity as in figure 23.

Pocket gophers.—There is little likelihood that pocket gophers would be exterminated from the area by any harvest treatment because they thrive on cutover lands. They kill small

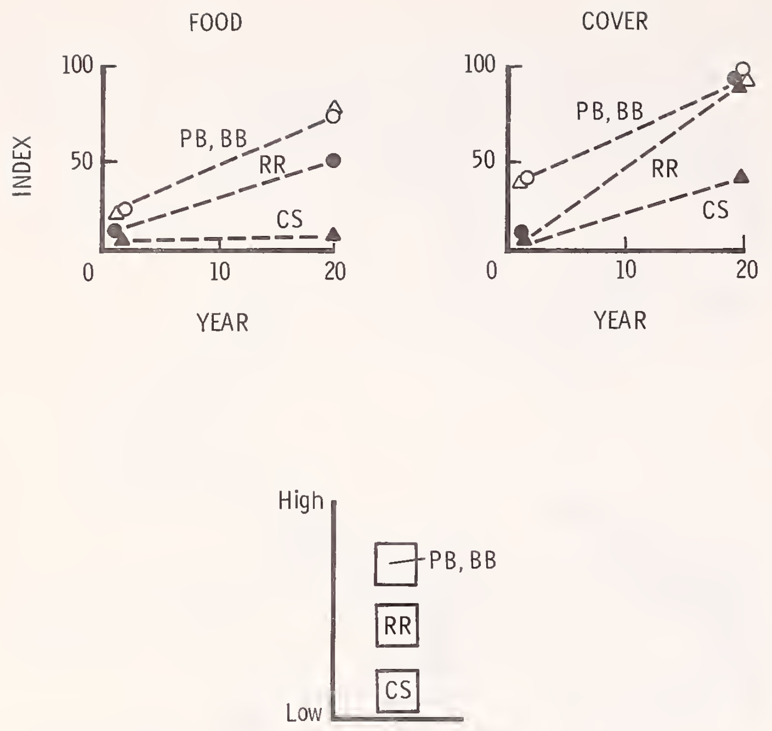


Figure 23.—Effect of treatments on bird habitat.

trees, but are valuable as food for carnivores and raptors. In this assessment, treatments favoring gophers are judged to be undesirable. Gophers feed on understory vegetation, so high vegetation production favors gopher population. Using this as a basis, the net effect of treatment on gophers is as shown in figure 24. The chip-spread treatment rates low because understory vegetation is retarded and gopher food limited. Other treatments are all higher because they provide ample gopher food; uncut stands are intermediate.

Other small rodents.—Mice, voles, and chipmunks have a negative impact on trees and other vegetation. They also are prey for predatory birds and animals that are valued by recreationists (coyote, bobcat, raptors, and so forth). Also, some rodents such as chipmunks are themselves valued for wildlife observation. In this analysis, therefore, these rodents are considered of moderate value, and neither extinction nor explosive overpopulation is likely in any treatment.

The index of population differences reported in SECOND RESPONSES can be portrayed as in figure 25. For several species no evaluations or trapping were made but their response to different treatments can be approximated. Red (pine) squirrels and flying squirrels will be displaced from all treatments until lodgepole reaches pole size or larger. Snowshoe hare and porcupines will increase on all treatments after trees are sapling size or larger.

Grazing Values

To protect regeneration, cattle grazing is not usually allowed in cutting units that have been planted to trees. All units of the study were fenced, and cattle have been kept out. Usually grazing is deferred until trees are 6 to 8 ft tall. With 2-0 planting stock this takes about 10 years and, therefore, the amount of herbage produced after age 10 can be used as an index for

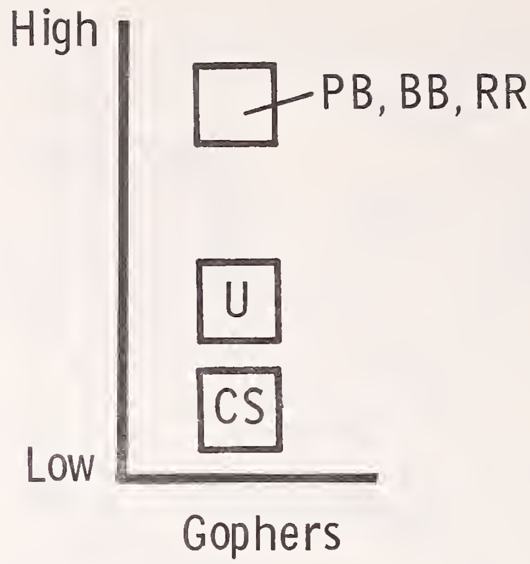


Figure 24.—Relative ranking of pocket gopher response to treatments.

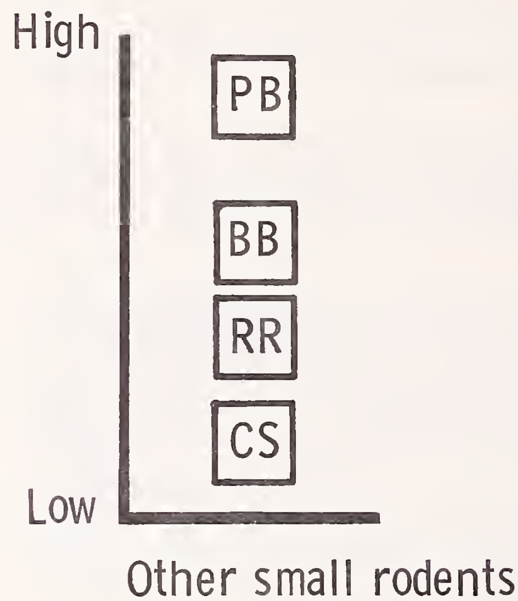


Figure 25.—Relative ranking of small rodent response to treatments.

comparing effects of treatment. The average amount of herbage produced per year for the period 10 to 25 years after harvest is projected to be:

Treatment	*Lb/acre*
Uncut	300
Residue-removed	650
Chip-spread	75
Broadcast burn	800
Pile/burn	700

These figures are derived by projecting the production for the study area as in figure 20 and averaging the annual production for the treatments for the period years 10 to 25. Although the residue-removed treatment initially produced more herbage than other treatments, by the 10th year all treatments except chip-spread are producing nearly the same.

In the case of forage for livestock, it is possible to convert forage production into a potential animal-unit-month (AUM) figure if the species, palatability, and nutritive value of the understory vegetation are available. These have not been determined specifically for the study area, but based on average forage values of similar vegetation elsewhere, and on estimates of forage availability, the potential for grazing can be expressed as in figure 26, using AUM's as the unit of value. AUM's are estimated from Forest Range Environmental Study (USDA Forest Service 1972) data which showed 288 lb/acre herbage average under lodgepole pine, and 152 acres/AUM. To simplify the comparisons, these values assume the cutover units are the only source of forage. Actual AUM/acre utilized would in practice probably be less than portrayed.

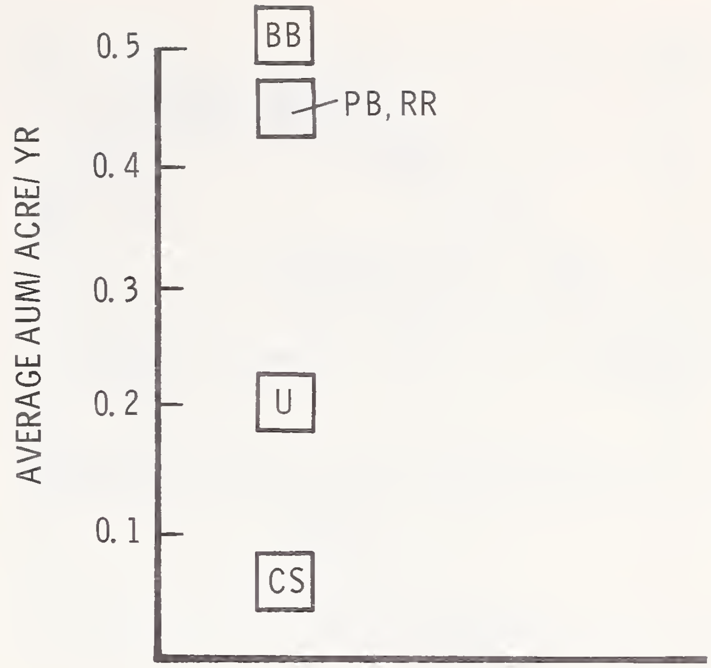


Figure 26.—Average AUM's per acre per year for the period 10 to 25 years after treatment.

Esthetic and Recreational Values

One objective of this study was to compare the logging and residue treatments in terms of esthetics. One phase of this evaluation was based on ratings given to color slides of the different treatments. The slides were taken from the viewpoint of an observer hiking or driving alongside the harvested units. In addition, managers evaluated how well each treatment might be suited to different recreation activities at the site. Distant-view esthetics, such as how well the shape or location of the units conformed to the general landscape, were not evaluated. Such considerations are, of course, important for any harvest operation.

PUBLIC VIEWER EVALUATION

The areas were evaluated using the Scenic Beauty Estimation (SBE) technique (Daniel and Boster 1976). Color slide photos of the areas were shown to panels of viewers who rated the slides on a scale of 0 ("dislike") to 9 ("like"). The viewers' ratings were mathematically transformed into scores that take into account the fact that some viewers use the rating scale differently than others. The transformed scores were then used to analyze the statistical significance of the ratings.

An arithmetic mean rating for each scene was also computed. The mean rating and the transformed score both indicate the same preference ranking among treatments. The arithmetic mean ratings are used here because they report results in the same units that viewers used in their ratings. Mean ratings for selected years after harvest were as follows:

	Panel "A"		Panel "B"		
	1st year	5th year	1st year	5th year	10th year
Meadow-forest edge (uncut)	-------7.43-------		-------------7.63-------------		
Residue-removed	3.09	3.61	3.35	4.39	4.62
Residue chipped and spread	2.71	2.25	2.11	2.71	4.31
Residue piled and burned	2.40	2.50	2.81	2.94	4.49
Residue broadcast burned	(not rated)	2.47	(not rated)	3.63	3.77

These are results from two of six panels that evaluated the treatments. Panel "A" did not evaluate the 10th year. Differences in means that exceed 0.86 for Panel "A" and 0.96 for Panel "B" are significant at 0.95 level.

Although ratings between panels are not statistically comparable, results were similar among all panels tested. A meadow-forest edge (not harvested), generally considered an appealing forest scene, was consistently rated much higher than harvested scenes. In the first year, all treatments were rated fairly low, with residue-removed somewhat higher. In the fifth year residue-removed was significantly higher, but in the 10th year all treatments were rated fairly close, and were significantly higher than earlier.

The SBE ratings do not reveal why the viewers initially rated the residue-removed treatment higher, or in year 10 other harvest treatments were about equal. However, other studies (Arthur 1977; Touzeau 1976) suggest two factors probably contributed. First, the residue-removed treatment had low (nearly ground level) stumps and large pieces of residue were absent, as compared with the higher stumps and partially burned large pieces in the burn treatments. Second, in the residue-removed units, roots and upper parts of forbs, grasses, and shrubs were left mostly intact and regrowth began to "green up" the area immediately. In the burn units this undergrowth was destroyed and in the chip-spread most was covered. By the 10th year understory vegetation and new seedlings were established, and covered much of the evidence of disturbance. New seedling growth was best in the pile and burn, and may have contributed to its improved rating in year 10 by screening the debris piles.

Figure 27 projects how esthetic rating might change over time, based on a separate study of viewer ratings (Panel "C") of slides of the study area and of lodgepole pine stands of different ages (Benson and Ullrich 1980). In this study the residue-removed treatment has some initial advantage over other treatments. When the young stands develop enough to cover any remaining logging debris or ground disturbance, the differences in ratings will probably diminish. The chip-spread areas were rated lower, and we would expect this to continue for as long as the chips retard regeneration. However, the combination of chip layer deterioration, moisture holding effects, and various changes in

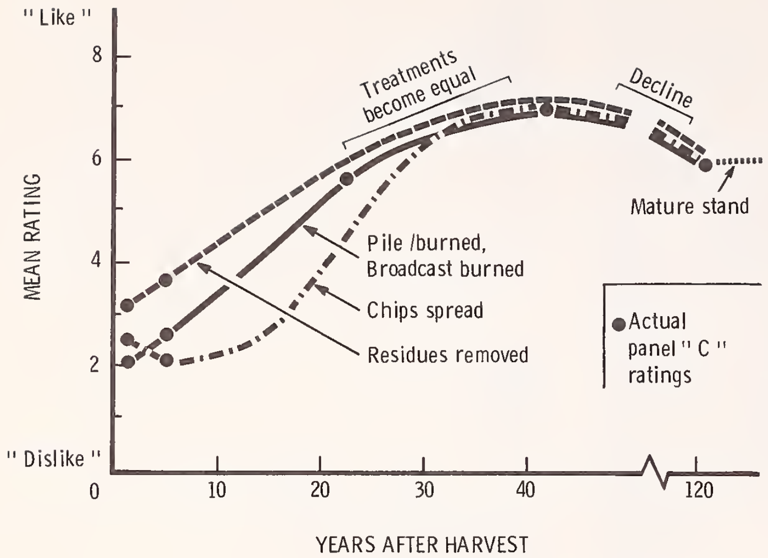


Figure 27.—Visual rating and projected trends for alternative residue treatments, lodgepole pine.

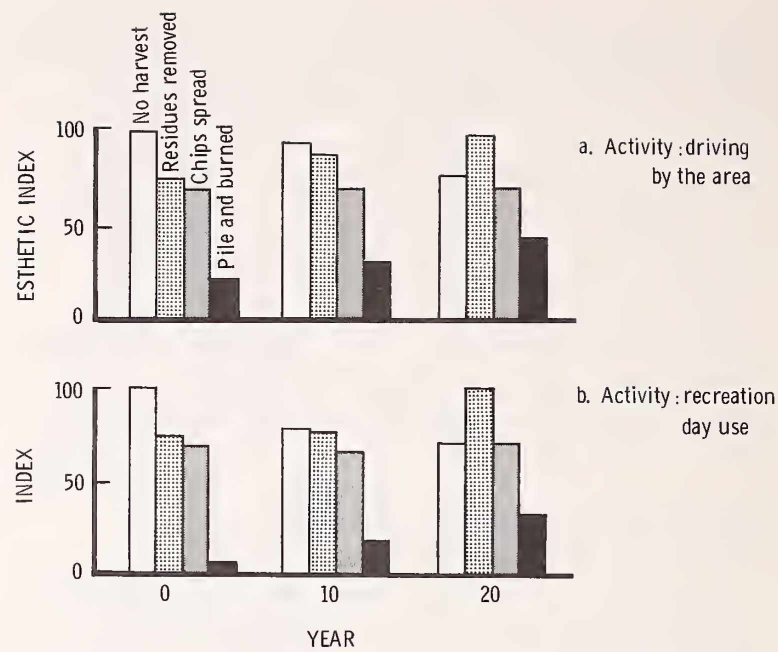


Figure 28.—Managers' evaluation of treatments for two recreation uses.

soil and water may alter this projected curve. In fact, the ratings by Panel "B" suggest differences have already notably diminished by the 10th year.

MANAGER EVALUATION

In a separate evaluation made the year after harvesting, Forest Service landscape managers appraised the treatments in terms of esthetics and recreation use, and rated the treatments on a scale of 0 to 100.[5] Evaluation for two typical recreation activities is shown in figure 28. In the pile/burn treatment, the activities that involved rapidly passing the area by car were rated higher than those where the viewer passed through more slowly. Lowest ratings for this treatment were for day-use recreation. Ratings for other recreation activities are in the appendix. In general, for a given treatment there was not much difference in the rating based on different type activities.

In addition to the rating immediately after harvest (year 0), projections were made as to esthetic response 10 to 20 years hence,[6] based on what would be seen driving by the areas. The ranking among treatments and the expected response over time were generally consistent with the SBE results obtained from the public viewer panels, even though the managers' evaluation preceded the SBE study by several years. Nevertheless, the managers' rating of residue-removed treatment was relatively higher than ratings by viewer panels.

Layout, location, and size of the cutting units were not directly part of the study, but under normal clearcutting practices, it is unlikely that different residue treatments would have much effect on general layout and design of cutting units.

The principal difference among the postharvest treatments is the proportion of the initial 20-year period that rates low on the scales. For the initial period of 20 years, a comparison of esthetic impact as a composite of both the managers' estimate of use opportunities and viewers' ratings can be portrayed as in figure 29.

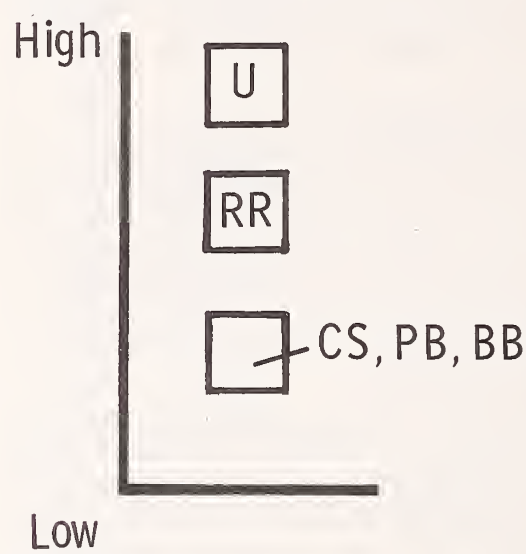


Figure 29.—Relative esthetic and recreation use opportunity.

Soil and Water

In the previous section, initial responses were compared in terms of soil and water chemistry, nutrients, and various soil properties. These factors work in combination to affect the basic condition of the site and its ultimate productive capacity.

Although there is a considerable background of information on soil productivity, depletion, and use (or abuse) regarding agricultural land, much less is known about forest land and the long-term effects of harvest and subsequent management activities. Because site factors are so complex, in many ways each

[5]Office report, "Wyoming Logging Residue Study—Esthetic and Recreation Evaluation," by Reed Stalder, USDA Forest Service. (On file at Forestry Sciences Laboratory, Missoula.) Activity viewpoints rated were: hiking-horseback, car travel, airplane, camping, from overlook, recreation day-use, and picture taking.

[6]Projections for 10 and 20 years hence were based on the expectation that plant succession and growth will be similar to that observed in adjacent areas following disturbance.

forest acre may be unique in its response to a given treatment. Furthermore, there is limited knowledge as to how sites change over time following harvest.

Despite the obvious limitations of a rather short-term study of treatments in one location, as this study involved, it is possible to hypothesize potential outcomes from the various treatments. The following section discusses this in terms of water, soil stability, nutrients, and site productivity.

Water quality.—As noted in the previous section, water quality was not substantially affected by the treatments. However, nitrates and phenols potentially could be of concern if they reach the aquatic environment or enter public water supplies in sufficient concentration. Also, erosion and siltation of streams would become important considerations if these treatments were applied on steeper terrain.

The most significant change in nitrates was in the pile/burn treatment, where levels in the soil solution increased to an average of 4.4 mg/liter, a fortyfold increase over the uncut forest. Although this level is not above the allowable threshold for potable water, the fact that nitrate levels can be changed so dramatically should serve to alert managers to the potential for pollution, and to the need to take this into account regarding the proximity of harvest units to ground or surface water that feed public water supplies.

In the chip-spread and residue-removed treatments relatively high phenol contents were present in the soil solutions during the first year, but declined sharply after that. If a cutting unit were located near a live stream and enough water were present to carry the phenols directly into the stream the first year, then potentially phenols would be present in amounts unacceptable for fisheries or water supplies.

The previous discussion of hydrology showed substantially higher soil movement in the scarified areas between burned piles (fig. 10). The terrain at the study site would result in virtually no chance for this to cause turbidity in any live water courses, but in steep terrain with more erodible soils, scarifying from logging can be a major source of silting in streams and turbidity of water. Soil movement was observed at the research plots under water applications that would correspond to cloudburst conditions, and the soil appeared to be moved only short distances within the site. This suggests that the pile/burn treatment might be considered slightly less desirable than the others in its impact on water quality for gentle terrain, but of more concern to water resource management under steeper conditions.

Site productivity.—It does not appear that the small amount of soil erosion, the nutrients lost in solution and in eroded soil from these treated sites, or the interruption of nutrient cycling will have a significant effect on growth rate or nutrition of the next crop of lodgepole pine. Over several centuries and many tree crops, however, enough nutrients might be lost through removal of residues to affect site quality. The greater the amount of material removed and utilized in a forest crop, especially if it is bark, needles, twigs, and seeds, the greater will be the quantity of nutrients removed from the site.

These factors raise two considerations regarding overall site productivity. First, early survival and growth of lodgepole pine is less on both the residue-removed and chip-spread treatments, and while the cause cannot be established from these studies, the increased level of phenolic compounds from these treatments suggests this could be a contributing factor. Second, and of a longer term nature, while a single harvest treatment does not appear to affect nutrients, repeated and intensive removal of biomass might. What this may mean from a practical standpoint is that no single factor—nutrients, phenols, soil movement, microsite effects, soil structure, or microorganisms—appeared to reach critical levels in this study situation. But if logging operations and residue treatments were applied in such a way that all the negative factors worked in concert, and were repeated through several cycles, long-term adverse effects to the site might result.

Because of the complexity and uncertainty posed by the long-term nature of these factors, it is highly speculative to compare treatments. Based on initial findings, however, treatments might be ranked on an index basis as in figure 30. The chip-spread and residue-removed treatments are rated slightly lower for water quality than the pile/burn because it is assumed that if some phenols did enter live water it would probably cause more concern than would the presence of some turbidity from soil movement. For overall site productivity, broadcast burning (which is close to natural burning conditions) is somewhat better than pile burning from which high nitrate levels and some soil loss may occur. Residue-removed and chip-spread rates were lower because of observed initial and potential long-term effects.

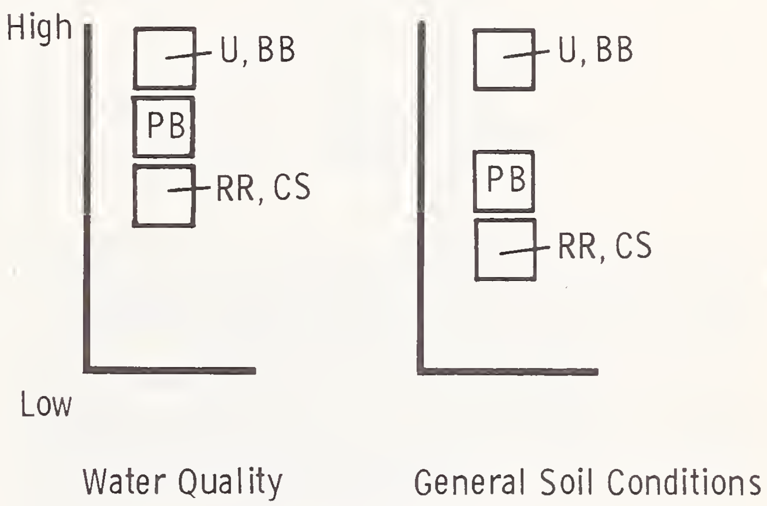


Figure 30.—Site response to alternative treatments.

Timber

The previous sections summarized harvesting activities and the regeneration, survival, and early growth of lodgepole pine after harvest. The immediate impacts of the alternative study treatments can be compared in terms of costs and returns for these activities. These are discussed in detail in the next section.

The stand projections presented earlier give an estimate of the kind of timber resource that will be grown for the next harvest. These projections indicate a considerable range in the nature of alternative future crops, with large cubic volumes in many small stems or fewer stems grown to saw log size (figs. 17 and 18; tables 14a and 14b) as potential outcomes.

Between these two time periods—the current, measurable results and the projected future harvest period 80 to 100 years hence—many uncertainties might alter the timber management situation (fire, disease, etc.). These have been alluded to in other sections. In addition, the stand may require thinning or other cultural work. Although no specific study was made, the different treatments have characteristics that are certain to influence intermediate cuttings. A high level of natural stocking is developing in the pile and burn treatments, not only in the

Table 15.—Net dollar values per acre of harvest and regeneration activities (1980 dollars)

		Uncut	Residue-removed	Chip-spread	Pile/burn	Broadcast burn
Timber value	Saw logs	0	1,994	1,994	1,994	1,994
	Chips	0	664	0	0	0
Subtotal		0	2,658	1,994	1,994	1,994
Harvest cost	Saw logs	0	725	725	725	725
	Chips	0	[1]705	[2]0	0	0
Subtotal		0	1,430	725	725	725
Net timber value		*0*	*1,228*	*1,269*	*1,269*	*1,269*
Slash treatment		0	0	[2]705	78	33
Planting		0	281	261	239	220
Fencing and rodent control		0	115	115	115	115
Subtotal		0	396	1,095	432	368
Net dollar value		*0*	*832*	*174*	*837*	*901*

[1]Chip cost treated as harvest cost because chips are recovered as a product, but could be considered as slash treatment.
[2]Cost of chipping is assigned to slash treatment because the residue stays onsite.

natural regeneration portion but in the seed spot and planted portions as well. If overstocking develops, projections based only on planted and seed spot stocking would be altered, and there may be a need for precommercial thinning.

Second, if there is a need for thinning or other stand entry, the method of slash disposal from the previous harvest may have a pronounced impact on the activity. The broadcast-burn units in particular were viewed as posing considerable difficulty for mechanical and possibly for manual thinning due to the large amount of charred residues remaining.[7] The same is true (but to a lesser extent) for the windrowed slash. This problem may tend to be aggravated by the fact that conditions for broadcast burning are not always ideal. The manager faces a high probability of either poor burning conditions that result in large amounts of unburned slash, or very dry conditions that threaten costly escaped fires. These factors are not an indictment of broadcast burning. Rather, they are considerations that could not be analyzed within the scope of the study.

The study area is typical of high elevation lodgepole pine and is not much affected by bark beetle infestations or dwarf mistletoe. Although many of the findings of this study, such as logging, utilization, and regeneration, may apply in other areas, the potential interaction between the treatments studied and insect and disease factors is not addressed.

Costs and Returns

Because of the uncertainties of future stand development and future costs and values, current costs and returns are used as a basis for comparing the different treatments. This analysis assumes that timber will be harvested on a 100-year rotation and therefore the dollar values are converted to a per-year basis; that is, the assumption is made that a continuing program of harvest would be followed and that for any given acre the net values per year would be the totals that accrue during a rotation, divided by 100 years.[8] Under these assumptions, the total costs and returns from the timber harvest, postharvest, and regeneration activities reported earlier are as shown in table 15. As noted in previous discussion, these costs are adjusted for initial stand volume differences, and updated to 1980 dollar basis.

Grazing, the one output in addition to timber that provides market values, is included in the cost and return summary. Grazing values are based on the projected understory vegetation development and are assumed to be harvested annually. In order to estimate grazing values, the average forage weights per year in each treatment are converted to animal unit months using the assumptions in the appendix. In this case, the assumption was made that, during a rotation period, any given acre will provide the following:

Year 1 - 10 = no forage or AUM's, since no grazing was allowed
Year 11 - 25 = forage and AUM's per year estimated from projections by treatment
Year 26 - rotation age = forage and AUM's estimated for mature lodgepole pine

[7]Based on communication from George Roether, R-4 Timber Management, and comments of other participants following field examination of the study sites in a workshop held in August 1981.

[8]It should be noted that for some purposes, an investment analysis that either compounded costs such as regeneration, or discounted future values, might be made.

Assuming a 100-year rotation, and the vegetation weights and AUM's, the total value per acre in grazing for the 100-year period is:

Uncut	$39.00
Residue-removed	42.00
Chip-spread	31.00
Pile/burn	43.00
Broadcast burn	45.00

There is not much difference among treatments in the grazing values because for so much (75 years) of the 100-year period, forage is at the level of uncut forest.

The timber and grazing values can be combined to produce a total net dollar value for the period. Alternatively, since nondollar values such as wildlife and esthetics are "produced" every year, the dollar values can be converted to an average annual value to provide a more equitable basis for comparing dollar and nondollar values. Total and average annual grazing and timber net values are:

	Value/acre 100-year period Timber	Grazing	Total	Annual (Total ÷ 100 yrs)
	Dollars/acre			
Uncut	0	39	39	0.39
Broadcast burn	901	45	946	9.46
Pile/burn	837	43	880	8.80
Residue-removed	832	42	874	8.74
Chip-spread	174	31	205	2.05

These annual costs and returns can be portrayed on the high-low scale as in figure 31. The net values represent the average annual return per acre, with costs and returns treated as current. As noted earlier, if some or all of the costs or returns were compounded or discounted, as in an investment analysis, the relationship of values could be different.

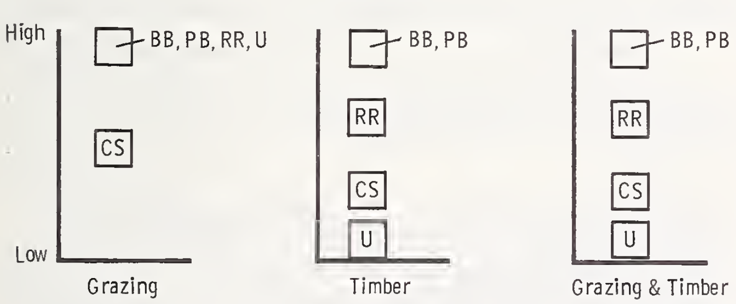


Figure 31.—Index of net dollar returns per acre per year.

MANAGEMENT IMPLICATIONS

If all the resources, harvest alternatives, and outcomes could be expressed in dollar values, it would be possible to extend data from the previous sections and derive a final comprehensive net value that could serve as a measure for comparing the harvest treatments. Unfortunately, many of the responses and use opportunities are not readily expressed in dollars. Furthermore, even the indexes developed may have different weights from one situation to the next, depending on which is of primary concern in the area. It is not possible to sum up the findings in such a way that the "best" harvest alternative is automatically identified. Nevertheless, two methods are presented for extending the analyses of nonmarket values and resource impacts to other situations.

Comparing Alternatives Using Net Dollar Returns and Nondollar Indexes

Harvesting alternatives in this study have resulted in different physical, biological, and net dollar return outcomes as described earlier. These dollar returns and indexes of nondollar responses can be compared as in figure 32 (Rickard and others 1967). The net dollar returns on the left are expressed as the net returns per acre per year, as derived in the previous section. On the right are the indexes of the various resources as use opportunities.

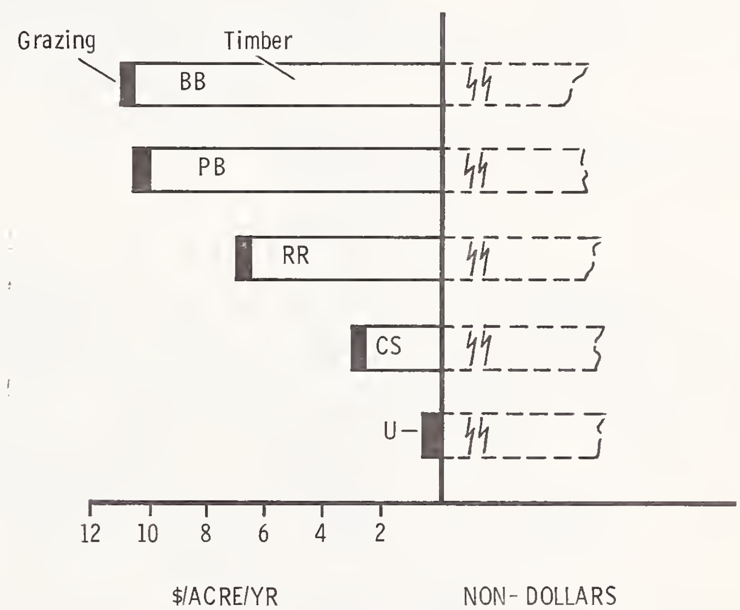


Figure 32.—Comparison of net dollar values of timber and grazing with nondollar values.

Visual comparison indicates that, considering one nondollar resource at a time, some alternatives are clearly superior to others even though the value of the noncommodity resources is not known. For example, in figures 33 through 35, broadcast burn is superior to every alternative except uncut, when considering small animal and bird habitat, water, and big-game cover. This is evident because both the dollar and nondollar bars either equal or exceed those of the other three alternatives. In the case of esthetics (fig. 36), pile/burn and chip-spread are inferior, but the other three alternatives are viable in that they represent trading off of net dollars against esthetic gains.

These comparisons do not by themselves indicate the best opportunity. For example, if harvest is planned, then the uncut option is not relevant even though it maximizes all of the nondollar values, at least in the short run. Nevertheless, to the extent realistic indexes can be developed, this analysis can compare dollar and nondollar outcomes for any individual use opportunity or resource.

Tradeoffs Among Alternatives

Although the analysis above illustrates the dollar and nondollar consequences of harvest alternatives for individual uses, frequently the interaction of several nonmarket values must be

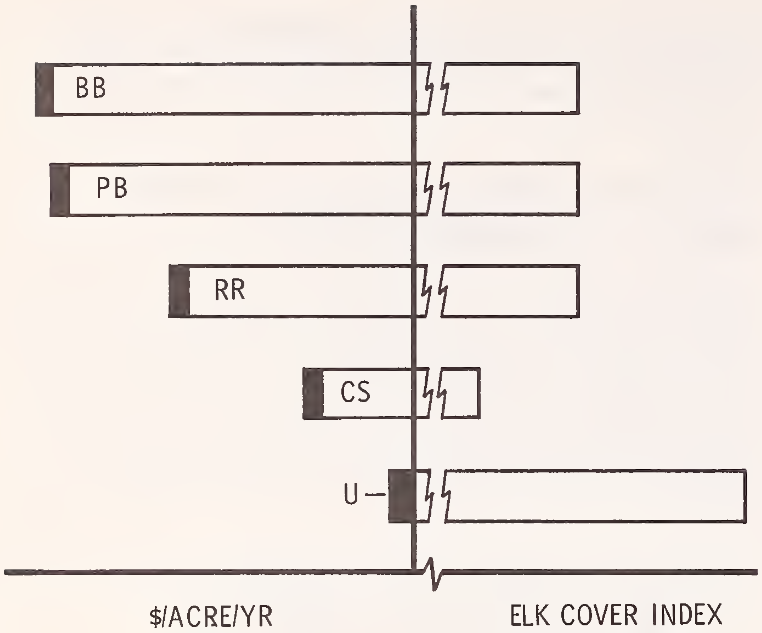


Figure 33.—Dollars and elk/moose cover.

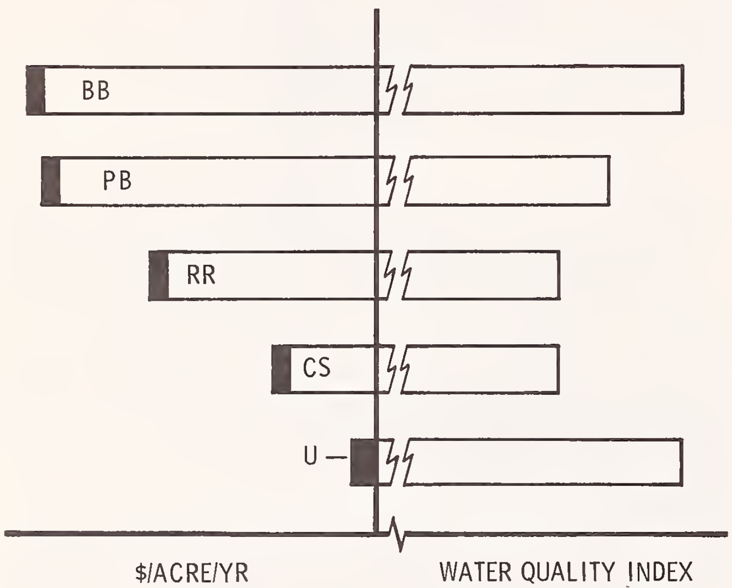


Figure 34.—Dollars and water quality.

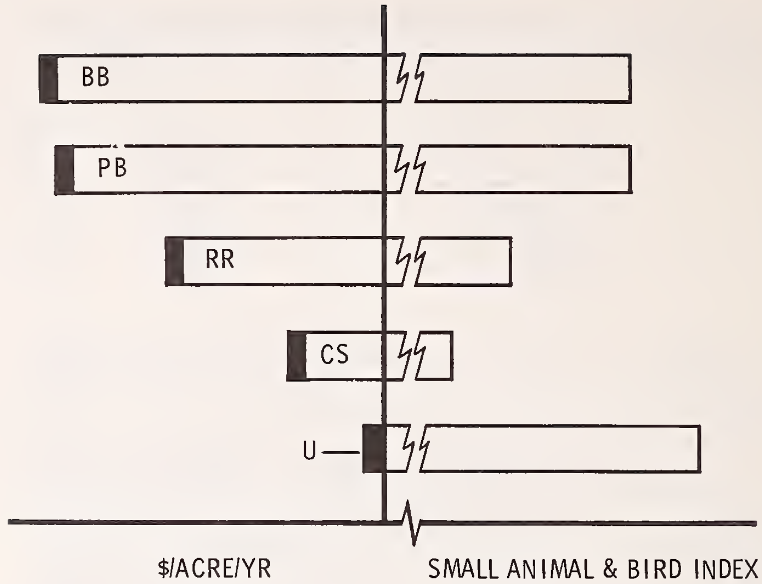


Figure 35.—Dollars and small animals and birds.

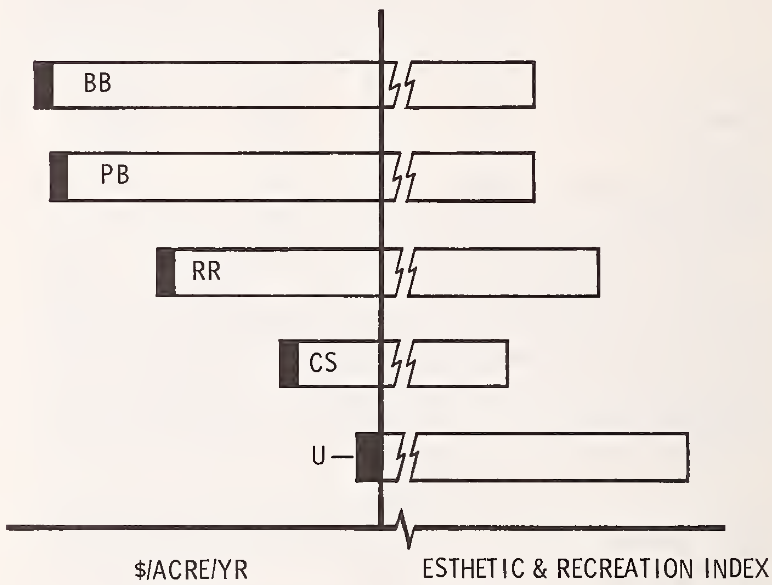


Figure 36.—Dollars and esthetics and recreation.

taken into account when analyzing harvesting alternatives. To take these into account in this study, the following steps are developed:

1. Identify potential interactions among uses.
2. Identify those interactions that might be affected by residue treatment.
3. Describe the interactions identified in 2 above in terms of tradeoffs.

Interactions between use opportunities that typically occur in a lodgepole pine situation such as the study area are summarized in table 16. The use being produced is listed across the top, and the use affected by the outputs is in the left column. Each cell in the matrix describes the nature of the interaction. For example, if an area is being used to produce timber (column 1), all other uses are affected by the amount and pattern of harvest, site preparation method used, and density of the newly developing forest. Water, on the other hand, may produce no appreciable impact on timber or grazing but can affect aquatic wildlife in terms of volume of runoff, its timing, and water quality.

Not all of the interactions are related to treatment differences. For example, in producing timber the harvest pattern (location, size, shaping, percent of area being harvested) affects all use opportunities, and may in fact, be the most important impact of harvesting. It is not analyzed here, however, because harvest pattern is not basically determined by residue treatment.[9]

Similarly, water is affected by grazing, wildlife, and recreation especially in the riparian zone, and since most timber harvest in this area is not now conducted in the riparian zone this interaction is not analyzed. Water may, however, be affected by timber activities, such as site preparation, or residue treatment. Earlier

[9]In other situations, residue treatment decisions might affect shape and location of cutting units; for example, broadcast burning in steep country where fire control is more difficult.

Table 16.—Interactions between use opportunities in a typical lodgepole pine forest

Each cell contains items, activity, or units involved in the interaction

USE BEING AFFECTED (to these)	USE BEING PRODUCED (from these)				
	TIMBER	**GRAZING**	**WILDLIFE**	**WATER**	**RECREATION**
TIMBER	X	AUM's year month	Gopher population Rodent population Seed-eating birds	Minor	Esthetics
GRAZING	Harvest pattern and percent of area Site preparation Tree density	X	Big game population Gopher population Rodent population	Minor	Disturbance to herd (function of people numbers)
WILDLIFE	Harvest pattern and percent Site preparation Tree density	AUM's year month	X	Volume Quality for aquatic life Timing	Disturbance Hunting
WATER	Harvest pattern and percent Site preparation Tree density	Temperature Chemistry (in riparian zone)	Temperature Chemistry (in riparian zone)	X	Temperature Chemistry (in riparian zone)
RECREATION	Harvest pattern and percent Site preparation Tree density	AUM's year month	Big game hunt Nongame species, numbers (bird watch, etc.)	Volume Quality Timing	X

Example of using table: **WILDLIFE** (being produced) interacts with **TIMBER** (being affected) in terms of gopher, other rodent, and seed-eating bird populations; but **TIMBER** (being produced) affects **WILDLIFE** through harvest patterns, percent of area cutover, site preparation method used, and density of trees.

sections presented some differences among treatments in their effect on water quality.

Some use opportunities that are most directly related to residue treatment and regeneration are listed in table 17, which describes the general nature of the interactions—competing, complementary, or both.

Using the high-low scales developed earlier, it is possible to show resource use opportunities for different combinations of resources under alternative treatments. In figure 37, four extremes of treatment alternatives are shown (that is, widely different combinations of resource use opportunities resulting from different treatments).

Generally, any array of treatments that falls along the line between a and b are complementary; both use opportunities are increased. Treatments along the line between x and y are competing; some of one use opportunity is given up to increase the other use opportunity. All other things being equal, the best treatment is one in which both use opportunities rate high (as treatment b); the worst is when both rate low (as treatment a). When the alternative treatments are arrayed along the x-y line, a decision must be made as to which is the better alternative. This may be based on comparing net dollar values of each, or the criteria may be more complex, involving some threshold of environmental acceptability or an amenity value, such as visual quality or songbirds. Thus, the comparisons shown in figure 37 can illustrate how indexes of resource use or response relate to each other, but may not provide dollar values or even a valuation scheme for some outputs.

In table 17 timber was identified as a use that interacts with all other resources and uses. Using net timber dollar values as an index, the interaction of timber with other outputs can be portrayed as in figure 38.

The "uncut" option rates low for timber because no wood is produced. Chip-spread is somewhat better because saw log values were recovered but the cost of chipping was incurred. Residue-removed is higher because some chip values are recovered to offset chipping costs. Pile/burn and broadcast burn rate highest.

The ratings for other resource uses are arrayed along the horizontal axis of figure 38. For small wildlife, pile/burn and broadcast burn are the best treatments in that they provide high use opportunities for both timber and small wildlife. For water, broadcast burn and uncut rate high, but others have some potential for adverse effects.

Timber vs. recreation esthetics represents a competing situation, at least in the short term. Uncut mature timber is clearly the best esthetic treatment; pile burning the worst esthetically but the

Table 17.—Interaction of use opportunities related to residue and regeneration treatments

Use being produced	Use being affected	Effect of residue/regeneration treatment on interaction
Timber	Grazing	**Competing** - (a) Treatments resulting in early, dense, and vigorous tree regeneration reduce grazing. (b) Fencing to protect trees reduces grazing.
	Wildlife (elk-deer-moose)	**Competing** - Regeneration reduces forage. **Complementary** - Regeneration increases hiding cover.
	Wildlife (small mammals and birds)	**Competing** - Treatments resulting in quick revegetation may attract rodents and require rodent control to protect trees. **Complementary** - Treatments providing predatory bird habitat may achieve balanced wildlife.
	Water (and aquatic life)	**Competing** - Burning or scarifying favors regeneration but adds turbidity/chemicals to water **Complementary** - Treatments resulting in quick, vigorous regeneration reduce water yields to the level of yields of uncut forest.
	Recreation	**Competing** - Initial site preparation by burning increases tree regeneration but decreases esthetics; residue-removed reduces tree revegetation. **Complementary** - Vigorous tree cover improves esthetic qualities.
Grazing	Timber	**Competing** - Methods that enhance forage and reduce trees extend grazing and decrease timber.
	Wildlife	**Complementary** - Methods producing forage favor large mammals. **Competing** - Methods enhancing grazing may reduce big-game use by "social" crowding.
Wildlife	Timber	**Competing** - (Timber vs. Wildlife above)
	Grazing	**Competing and Complementary** - (see above)
	Recreation	**Complementary and Competing**
Water	Wildlife and recreation	**Indeterminant** - All residue treatments have potential adverse effects.
Recreation	Timber	**Competing** - Most immediately acceptable esthetic treatment, residue-removed may retard regeneration/growth. **Complementary** - More rapid regeneration/growth of trees speeds up esthetic response in the long run.

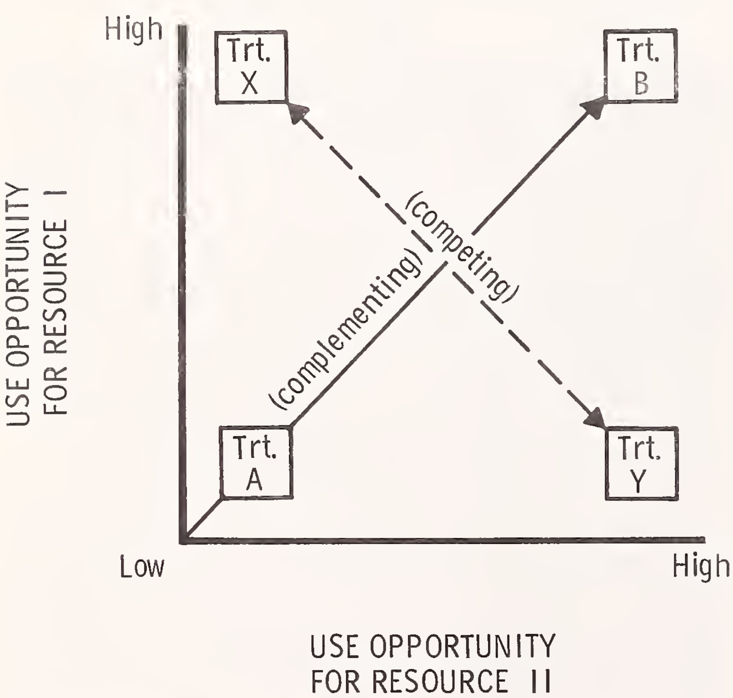


Figure 37.—Resource use opportunities under alternative treatments.

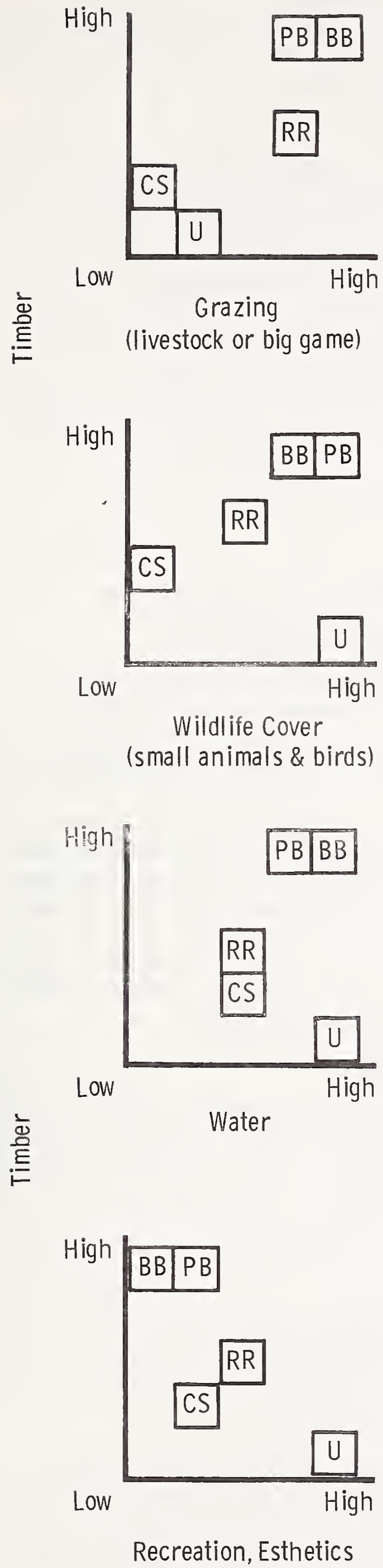
best for timber. (Note that the comparisons pertain to the first 25 years after treatment and, therefore, the attractive "greening" of young pole stands is not reflected.)

In this situation, the manager of a highly sensitive visual area may opt for no harvest or for removing residues with residue-removed utilization, regardless of the timber values foregone. In another situation he may decide higher timber values gained through burning residues can justify some loss of esthetic quality.

For big-game animal forage there is an indeterminate relationship with timber. Pile/burn and broadcast burn are fairly high in both outputs; chip-spread and uncut stands are relatively low, and residue-removed is intermediate.

Figures 39 and 40 portray the typical relationship between other resources as listed in table 17. Even without attempting to weigh the various outputs, these figures illustrate that some treatments are obviously superior to others for given resource combinations. For example, if timber revenues and wildlife cover are the two most critical resource outputs, it is obvious that pile/burn and broadcast burn provide more of both than any of the other treatments.

Timber revenues and esthetic quality present a different situation. Here all treatments except chip-spread fall along a "competing" or "tradeoff" line. Moving from uncut, which is high in esthetic quality and low in timber revenues, sacrifices esthetic value to gain timber value. Chip-spread, which lies closer to the



a. Cattle, large animals and vegetation-eating rodents are favored by BB which has the highest forage output.

b. Small animals and birds have better cover where some debris remains.

c. Piling has some negative potential for nitrates and turbidity. RR and CS have some potential for phenols in water.

d. Most treatments align as competing.

Figure 38.—Interaction of timber and other outputs.

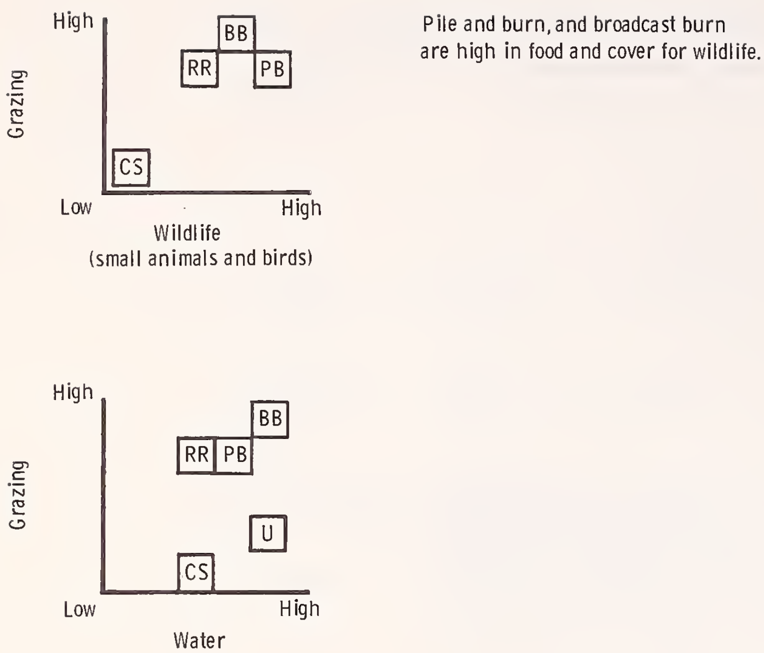


Figure 39.—Interaction of grazing and other uses.

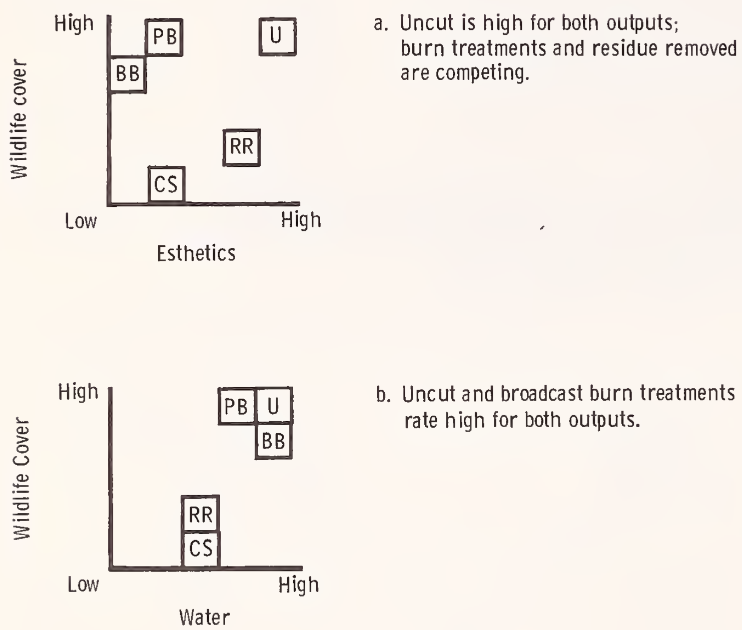


Figure 40.—Interaction of wildlife with other resource outputs.

lowest point on both scales, is clearly inferior; it can provide more recreation value than the burn treatments, but the residue-removed treatment provides even more recreation value plus high timber revenues.

Figure 40a shows a different situation; uncut is clearly superior for both wildlife and recreation, but burning and residue-removed are competing. In 40b, uncut and broadcast burn are both slightly better than pile/burn, and all three are definitely superior to chip-spread and residue-removed if wildlife and water are the concern.

These simple graphic comparisons are useful only if in fact they reflect realistic situations. Recalling that the slightly negative impacts on water quality were based on the small chance that turbidity, nitrates, or phenols would reach live water in level land, it may be more realistic to rate all treatments at the highest end of the scale (no negative impacts). In this case, water could be omitted as a basis for comparison. Conversely, on steep ground or near water courses where any pollutants are unacceptable, all treatments may be rated low on the water scale.

In addition, some treatments may not be relevant. In the wildlife-recreation combination the uncut stand is clearly superior. If the decision has already been made to harvest, however, then the next best options are among pile/burn, broadcast burn, or residue-removed, which are along the tradeoff line.

As in all analyses that are aimed at aiding decisions, this simple process is useful only to the extent assumptions are valid and conditions remain stable. The ultimate decision is up to the manager, and part of his decision process should be to speculate on the sensitivity of the analyses to change, probabilities of projected outcomes, and other factors not included in the analyses model. For example, the real probability of achieving a successful broadcast burn under normal day-to-day operations may be low enough that the manager would opt for pile burning even though the net timber values are less. Or, the value of residues may rise to the point that removing them becomes a more attractive alternative in the tradeoff analyses.

Summary of Treatments

This report describes harvest and regeneration alternatives and analyzes their impacts, as observed on the study site. In addition, the effect of treatments on several principal resources and use opportunities has been described, and interactions and tradeoffs identified.

There is no single "best" alternative among those studied; a treatment that benefits one resource may be adverse for another resource. The brief summary of each treatment that follows is, however, based only on the effects on individual resources, not on tradeoffs and interactions. In addition, the summaries include comments on some aspects that were not formally studied, but that have been identified as potentially important considerations in appraising the treatments.

PILE/BURN

Pile/burn, the standard conventional treatment of logging residues in the area, produced the most successful regeneration. It rated high in net timber revenues from harvest and in projected future stand volume. Scarification between piles resulted in more potential for erosion and removal of organic material and surface soil may reduce site quality between piles. A moderate amount of understory vegetation was produced in the first years after harvest and, together with debris in the piles, provided food and cover for small birds and ground-dwelling rodents (gophers, mice, etc.). The visual impact is harsh, and this appears to persist as long as partially burned piles are visible.

BROADCAST BURN

For the most part broadcast burning is similar to pile/burn, except net timber revenues are slightly higher because of lower slash disposal costs. Visual impact and wildlife cover and forage were about the same as with pile/burn. There was less soil compaction and surface erosion, but most soil nutrients and organic matter were similar to the pile/burn treatment except that nutrients were not concentrated into piles. Survival and growth of planted seedlings and of natural regeneration was slightly less successful than in the pile/burn treatment, but spot seeding success was higher.

Projected future stand development is about the same as pile/burn. The persistence of partially burned large residues over the area could adversely affect future stand entry for thinning or other management needs.

RESIDUE-REMOVED

In the actual study there was no available market for residues chipped onsite, but assuming a chip market and average chip price, the net timber revenues of this treatment are about the same as with broadcast burning. One notable effect of this treatment was substantially less success of planted seedlings and seed spots than the burned treatments, but good natural regeneration. There was more understory vegetation in the years immediately after harvest, but the absence of logging debris means less cover for wildlife. This treatment rated highest in visual preferences up through the fifth year after harvest. Phenol concentration in soil water was quite high under this treatment during the first year, but declined rapidly.

CHIP-SPREAD

Chip-spread had substantially lower net timber revenues because the cost of chipping was incurred but no chip values were received. Survival and growth of planted trees and seed regeneration was drastically impaired the first years, but growth of surviving trees has since mostly recovered. The projected future stand has fewer but larger trees, and volumes similar to other treatments. Understory vegetation is virtually absent the first 5 years and, therefore, wildlife habitat for all species severely impaired. The visual quality of this treatment was slightly better than burn treatments initially, but has not improved much since. Phenol concentrations increased markedly during the first year, and could affect water quality if this treatment were near running water courses. Potential for overland flow and erosion is virtually nil.

An Update and Overview

In the decade since this study was initiated, three major changes have occurred that bear on the interpretation and extrapolation of the study results:

1. The utilization of dead material that constituted much of the residues on the study site and in all overmature lodgepole stands, has greatly expanded both for round wood and sawed products. The effect on net timber revenues varies, depending on local markets and value of dead material, but generally revenues from saw logs and residues would be higher for all treatments if the study were conducted today.
2. The dramatic increase in fuel costs reduces the feasibility of chipping residues and spreading back on the ground. Although no direct estimation was made of fuel consumption, it is likely that skidding residues to the chipper, chipping, and then some additional spreading would consume more fuel than the single step of piling residues or broadcast burning.
3. Withdrawal of some forest lands from the timber-growing base and other constraints has increased interest in improving productivity on those lands managed for timber. Two important questions remain unanswered. First, the actual growth and development of the new stands on the different treatments: initial differences are expected to diminish, but only continued observation will verify this. Second, the need for and costs of thinning or other work can only be speculated at this time. As noted earlier, the broadcast-burn treatment had many favorable results, but could potentially increase costs of next entry. This is an important speculation that should be pursued. The chip-spread treatment appears to impair initial stand development, but if projected stocking prevails, it could reduce the need for intermediate thinning. Again, verifying this speculation and comparing costs and benefits is an important but yet unanswered part of evaluating this type of residue disposal.

In summary, then, this study has provided some initial evaluations of four residue treatments and three regeneration methods, but continued monitoring of the study area is needed to complete the evaluation and draw additional management information.

PUBLICATIONS CITED

Alexander, Robert R. Establishment of lodgepole pine reproduction after different slash disposal treatments. Res. Note RM-62, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 4 p.

Arthur, Louise M. Predicting scenic beauty of forest environments: some empirical tests. For. Sci. 23: 151-159; 1977.

Baker, F. S. Effect of excessively high temperatures on coniferous reproduction. J. For. 27: 949-975; 1929.

Bartos, D. L.; Mueggler, W. F. Influence of fire on vegetation production in the aspen ecosystem in western Wyoming. In: Boyce, M. S.; Hayden-Wing, L. D., eds. North American elk: behavior and management. Laramie: University of Wyoming Press; 1979: 75-78.

Basile, Joseph V.; Jensen, Chester. Grazing potential on lodgepole pine clearcuts in Montana. Res. Pap. INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 11 p.

Bate-Smith, E. C. Simple polyphenolic constituents of plants. In: Hillis, W. F., ed. Wood extractives and their significance to the pulp and paper industry. New York: Academic Press; 1962: 133-158.

Benson, Robert E. Lodgepole pine logging residues: management alternatives. Res. Pap. INT-160. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 28 p.

Benson, Robert E.; Ullrich, James R. Visual impacts of forest management activities: findings on public preferences. Res. Pap. INT-262. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 14 p.

Blanchette, R. A.; Shaw, C. G. Management of forest residues for rapid decay. Can. J. Bot. 56: 2904-2909; 1978.

Brown, James K. Reduction of fire potential in lodgepole pine due to more complete utilization. Res. Note INT-181. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 6 p.

Cochran, P. H.; Bernsten, Carl M. Tolerance of lodgepole and ponderosa pine seedlings to low night temperatures. For. Sci. 19: 272-280; 1973.

Daniel, Terry C.; Boster, Ron S. Measuring landscape esthetics: the scenic beauty estimation method. Res. Pap. RM-167. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1976. 66 p.

DeByle, Norbert V. Harvesting and site treatment influences on the nutrient status of lodgepole pine forests in western Wyoming. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 137-156.

DeGroot, R. C. Phenolic extractives in lateral branches and injured leaders of *Pinus strobus* L. Can. J. Bot. 44: 57-61; 1966.

Demos, E. K.; Woolwine, M.; Wilson, R. H.; McMillan, C. The effects of ten phenolic compounds on hypocotyl growth and mitochondrial metabolism of Mung bean. Am. J. Bot. 62: 97-102; 1975.

Fisher, Richard B. Allelopathy: a potential cause of regeneration failure. J. For. 78(6): 346-348, 350; 1980.

Foulger, A. N.; Harris, Johnny. Volume of wood, bark, and needles after clearcutting a lodgepole pine stand. J. For. 71(2): 93-95; 1973.

Faurot, James L. Estimating merchantable volume and stem residue in four timber species. Res. Pap. INT-196. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 55 p.

Gadgil, R. L.; Gadgil, P. D. Influence of clearfelling on decomposition of *Pinus radiata* litter. N.Z. J. For. Sci. 8: 213-224; 1978.

Galbraith, Marlin C. Environmental effects of timber harvest and utilization of logging residues. Environmental Affairs (Boston College Environmental Law Center) 11(2): 314-331; 1972.

Gardner, R. B.; Hartsog, W. S. Logging equipment, methods, and cost for near-complete harvesting of lodgepole pine in Wyoming. Res. Note INT-147. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 15 p.

Gardner, Rulon B.; Hann, David W. Utilization of lodgepole pine logging residues in Wyoming increases fiber yield. Res. Note INT-160. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 6 p.

Hare, Robert C. Heat effects on living plants. Occas. Pap. 183. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1961.

Hart, George E.; DeByle, Norbert V. Effects of lodgepole pine logging and residue disposal on subsurface water chemistry. In: Watershed management symposium: proceedings; 1975 August 11-13; Logan, UT. American Society of Civil Engineers, Irrigation and Drainage Division; 1975: 98-109.

Hart, George E.; DeByle, Norbert V.; Hennes, Robert W. Slash treatment after clearcutting lodgepole pine affects nutrients in soil water. J. For. 79(7): 446-450; 1981.

Harvey, A. E.; Jurgensen, M. F.; Larsen, M. J. Intensive fiber utilization and prescribed fire: effects on the microbial ecology of forests. Gen. Tech. Rep. INT-28. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976. 46 p.

Harvey, A. E.; Jurgensen, M. F.; Larsen, M. J. Clearcut harvesting and ectomycorrhizae: survival of activity on residual roots and influence on a bordering forest stand in western Montana. Can. J. For. Res. 10: 300-303; 1980.

Harvey, A. E.; Larsen, M. J.; Jurgensen, M. F. Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat types. For. Sci. 25: 350-358; 1979.

Harvey, A. E.; Larsen, M. J.; Jurgensen, M. F. Ecology of ectomycorrhizae in northern Rocky Mountain forests. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 189-208.

Hungerford, Roger D. Microenvironmental response to harvesting and residue management. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 37-74.

Jorgensen, Erik. The formation of pinosylvin and its monethyl ether in the sapwood of *Pinus resinosa* Ait. Can. J. Bot. 39: 1765-1772; 1961.

Jurgensen, M. F.; Arno, S. F.; Harvey, A. E.; Larsen, M. J.; Pfister, R. D. Symbiotic and non-symbiotic nitrogen fixation in northern Rocky Mountain forest ecosystems. In: Gordon, J.; Wheeler, C.; Perry, D. eds. Symbiotic nitrogen fixation in the management of temperate forests. Corvallis: Oregon State Univ. Press; 1979: 294-308.

Jurgensen, M. F.; Larsen, M. J.; Harvey, A. E. A soil sampler for steep rocky sites. Res. Note INT-217. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 5 p.

Jurgensen, M. F.; Larsen, M. J.; Harvey, A. E. Forest soil biology - timber harvesting relationships. Gen. Tech. Rep. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 1979. 12 p.

Jurgensen, M. F.; Larsen, M. J.; Harvey, A. E. Microbial processes associated with nitrogen cycling in northern Rocky Mountain forest soils. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 175-188.

Larsen, M. J.; Jurgensen, M. F.; Harvey, A. E. N_2 fixation associated with wood decay by some common fungi in western Montana. Can. J. For. Res. 8: 341-345; 1978.

Lotan, James E. Initial germination and survival of lodgepole pine on prepared seedbeds. Res. Note INT-29. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1964. 8 p.

Lotan, James E.; Dahlgreen, Allen K. Hand preparation of seedbeds improves spot seeding of lodgepole pine in Wyoming. Res. Note INT-148. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 7 p.

Lotan, James E.; Perry, David. Effects of utilization on regeneration of lodgepole pine clearcuts. In: Symposium on terrestrial and aquatic ecological studies of the Northwest: proceedings; 1976 March 26-27. Cheney, WA: Eastern Washington State College; 1976: 125-133.

Mensah, K. O. A. Allelopathy as expressed by sugar maple on yellow birch. Ann Arbor, MI: University of Michigan; 1972. 105 p. Ph.D. thesis.

Michniewicz, M.; Galoch, E. The role of vanillin and p-coumaric acid in the growth of Scotch pine seedlings. Acta Societatis Botanicorum Poloniae XLIII; 1974.

Moore, W. E.; Johnson, D. B. Procedures for the chemical analysis of wood and wood products (at the U.S. Forest Products Laboratory). Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1967 (rev.). Unpublished report.

Mroz, G. D.; Jurgensen, M. F.; Harvey, A. E.; Larsen, M. J. Effects of pine on nitrogen in forest floor horizons. Soil Sci. Soc. Am. J. 44: 345-400; 1980.

Myers, Clifford A.; Hawksworth, Frank; Stewart, James L. Simulating yields of managed dwarfmistletoe-infected lodgepole pine stands. Res. Pap. RM-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 15 p.

Packer, Paul; Williams, Bryan D. Logging residue disposal effects on surface hydrology and soil stability of lodgepole pine forests. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 111-122.

Puckett, John V.; Johnston, Cameron M.; Albini, Frank A.; Brown, James K.; Bunnell, David L.; Fischer, William C.; Snell, J. A. Kendell. Users' guide to debris prediction and hazard appraisal. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1979. Mimeo report.

Rickard, Wesley; Hughes, Jay M.; Newport, Carl A. Economic evaluation and choice in old growth Douglas-fir landscape management. Res. Pap. PNW-49. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1967. 33 p.

Rothermel, Richard. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 40 p.

Schmidt, Wyman C. Seedbed treatments influence seedling development in western larch forests. Res. Note INT-93. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 7 p.

Schmidt, Wyman C.; Lotan, James E. Establishment and initial development of lodgepole pine in response to residue management. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 270-286.

Schmidt, Wyman C.; Shearer, Raymond C.; Roe, Arthur L. Ecology and silviculture of western larch forests. Tech. Bull. 1520. Washington, DC: U.S. Department of Agriculture; 1976. 96 p.

Shearer, Raymond C. Early establishment of conifers following prescribed broadcast burning in western larch/Douglas-fir forests. In: Proceedings tall timbers fire ecology conference and fire and land management symposium; 1974 October 8-10; Missoula, MT: Tallahassee, FL: Tall Timbers Research Station; 1976: 481-500.

Steele, Robert; Cooper, Stephen; Ondov, David; Pfister, Robert. Forest habitat types of eastern Idaho-western Wyoming. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. Review draft.

Touzeau, Roy F. Scaling perceptions and preferences of forest scenes from Coram Experimental Forest: an application of multidimensional scaling. Missoula, MT: University of Montana; 1976. 325 p. Thesis.

USDA Forest Service. The Nation's range resources: a forest range-environmental study. For. Resour. Rep. 19. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972. 147 p.

Wells, C. J.; Campbell, R. E.; DeBano, L. F.; Lewis, C. E.; Fredericksen, R. L.; Franklin, E. C.; Forelich, R. C.; Dunn, P. H. Effects of fire on soil: a state-of-knowledge review. Gen. Tech. Rep. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 34 p.

APPENDIX

Table 18.—Number of trees per acre, preharvest, by species, diameter class, and condition

	Unit			
	1	2	3	4
	Number of stems			
Live trees < 5 in d.b.h.				
Subalpine fir	300	474	236	277
Engelmann spruce	48	39	72	300
Lodgepole pine	420	39	54	108
Whitebark/limber pine	1,176	1,548	1,482	731
Subtotal, per acre	1,944	2,100	1,844	1,416
(per hectare)	(4 802)	(5 187)	(4 555)	(3 497)
Live trees 5.0 in - 8.9 in				
Subalpine fir	17	8	20	20
Engelmann spruce	21	4	13	6
Lodgepole pine	74	131	59	53
Whitebark/limber pine	0	0	5	11
Subtotal, per acre	112	143	97	90
(per hectare)	(277)	(353)	(240)	(222)
Live trees 9.0 + in				
Subalpine fir	4	7	16	16
Engelmann spruce	2	3	10	36
Lodgepole pine	172	212	155	90
Whitebark/limber pine	0	18	2	7
Subtotal, per acre	178	240	183	149
(per hectare)	(440)	(593)	(452)	(368)
Total live, per acre	2,234	2,483	2,124	1,655
(per hectare)	(5 518)	(6 133)	(5 246)	(4 088)
Dead trees, < 5 in	48	10	0	8
Dead trees, 5.0 + in				
Lodgepole pine	119	132	54	50
Other	0	0	2	5
Total dead, per acre	167	142	56	63
(per hectare)	(412)	(351)	(138)	(156)

Table 19.—Preharvest volume by component and cutting unit

	Conventional util			Residue-removed		
	Unit 2	Unit 3	Average	Unit 1	Unit 4	Average
Live, standing, to 6 in-top, ft³/acre	7,167	6,131	6,649	5,912	5,184	5,547
Dead, standing, to 6 in-top, ft³/acre	1,016	1,120	1,048	1,014	1,064	1,039
Subtotal, to 6-in top, ft³/acre	8,183	7,251	7,717	6,926	6,246	6,586
(m³/ha)	(573)	(508)	(540)	(485)	(437)	(461)
Tree residuals,[1] ft³/acre	1,460	797	1,128	1,124	752	938
(m³/ha)	(102)	(56)	(79)	(79)	(53)	(66)
Down, ft³/acre	1,182	1,478	1,330	1,820	2,482	2,151
(m³/ha)	(83)	(103)	(93)	(127)	(174)	(151)
Total, 3+ in, ft³/acre	10,825	9,526	10,175	9,870	9,480	9,675
(m³/ha)	(758)	(667)	(712)	(691)	(664)	(677)

[1]Includes total volume of trees 3.0 in (7.6 cm) to 6.4 in (16.4 cm) d.b.h.; plus volume between 6.0 in (15.2 cm) and 3.0 in (7.6 cm) top, for trees 6.5 in (16.5 cm) d.b.h. and larger.

Source: Gardner and Hann 1972

Table 20.—Preharvest volume by merchantability group

	Conventional util			Residue-removed		
	Unit 2	Unit 3	Average	Unit 1	Unit 4	Average
Merchantable						
Live, to 6 in-top, ft³/acre	7,167	6,131	6,649	5,912	5,182	5,547
Dead, to 6 in-top, ft³/acre	1,016	1,080	1,048	1,014	1,064	1,039
Total, ft³/acre	8,183	7,211	7,697	6,926	6,246	6,586
(m³/ha)	(573)	(505)	(539)	(485)	(437)	(461)
Saw logs, M bd.ft./acre	24.9	22.0	23.4	20.5	18.7	19.6
Residues						
Tree residual						
Green, ft³/acre	975	672	824	707	643	675
Sound dead, ft³/acre	485	123	304	312	24	168
Down, sound, ft³/acre	509	629	569	965	955	960
Subtotal	1,969	1,424	1,697	1,984	1,622	1,803
(m³/ha)	(138)	(100)	(119)	(139)	(114)	(126)
Unsound, ft³/acre	673	890	781	960	1,612	1,286
(m³/ha)	(47)	(62)	(55)	(67)	(113)	(90)
Total, 3+ in, ft³/acre	10,825	9,526	10,175	9,870	9,480	9,675
(m³/ha)	(758)	(667)	(712)	(691)	(664)	(677)

Table 21.—Weight of fine material: Preharvest

Unit	Size	AF	ES	LP	WB/LP	Total	Down[2]	Duff[3]	Understory[4] vegetation	Total all fines
		Dry weight of material, tons/acre (t/ha)								
		Tree crowns[1]								
1	Foliage	0.572	0.397	1.788	0.002	2.759				
	0'' - ¼''	.320	.218	1.565	.002		0.252			
	¼'' - 1''	.456	.226	1.868	.002		1.469			
	1'' - 3''	.092	.082	1.486	.001		3.142			
	Total	1.440	0.923	6.707	0.007	9.077	4.863	10.745	0.177	24.862
		(3.23)	(2.07)	(15.03)	(.02)	(20.30)	(10.90)	(24.10)	(.40)	(55.73)
2	Foliage	0.521	0.199	2.401	0.195					
	0'' - ¼''	.308	.118	2.064	.183		0.276			
	¼'' - 1''	.468	.138	2.532	.215		1.595			
	1'' - 3''	.091	.081	1.998	.227		3.681			
	Total	1.388	0.536	8.986	0.820	11.730	5.552	12.255	0.177	29.714
		(3.11)	(1.20)	(20.14)	(1.84)	(26.30)	(12.44)	(27.47)	(.40)	(66.61)
3	Foliage	0.942	0.865	1.626	0.002					
	0'' - ¼''	.564	.523	1.446	.002		0.351			
	¼'' - 1''	.874	.684	1.771	.001		1.480			
	1'' - 3''	.181	.477	1.565	—		3.344			
	Total	2.561	2.549	6.408	0.005	11.523	5.175	14.607	0.109	31.414
		(5.74)	(5.71)	(14.36)	(.01)	(3.41)	(11.60)	(32.74)	(.24)	(70.42)
4	Foliage	0.698	1.535	1.353	0.182					
	0'' - ¼''	.456	.964	1.210	.146		0.222			
	¼'' - 1''	.824	1.408	1.475	.173		1.083			
	1'' - 3''	.180	1.098	1.312	.085		2.502			
	Total	2.158	5.005	5.350	0.586	13.099	3.807	15.783	0.036	32.725
		(4.84)	(11.22)	(11.99)	(1.31)	(29.36)	(8.53)	(35.38)	(.08)	(73.36)

[1]Total weight by species from Gardner and Hann 1972; size classes estimated using Brown 1976.
[2]Material < 3-in diameter (7.6 cm); total weight from Hann 1972; size classes apportioned.
[3]From Gardner and Hann 1972, duff depths using specific gravity of 0.125.
[4]Schmidt and Lotan 1980.

Table 22.—Ground cover, fuel depth, and duff depth by unit, pre- and postharvest, first year[1]

Ground cover[2]	Unit 1		Unit 2		Unit 3		Unit 4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Percent							
Mineral soil	2	37	[3]	26	1	32	2	48
Rock	0	0	0	0	0	0	1	0
Needles	46	32	53	41	49	40	50	21
Wood	28	31	21	32	17	27	14	31
Moss	0	0	0	0		0	0	0
Grass	20	0	9	[3]	17	[3]	24	[3]
Brush	3	0	17	0	15	7	8	0
Total	100	100	100	100	100	100	100	100
Fuel depth, inches	21.4	2.1	14.6	7.4	12.7	7.4	10.3	3.6
(cm)	(54.3)	(3.3)	(5.3)	(18.8)	(32.2)	(18.8)	(26.2)	(9.1)
Duff depth,[4] inches	0.74	—	0.84	—	1.00	—	1.10	—
(cm)	(1.9)		(2.13)		(2.54)		(2.8)	

[1]Source: Resources Evaluation Work Unit, INT-Ogden (data on file, INT, Missoula).
[2]Items may not total 100 percent due to rounding.
[3]Less than 0.5 percent.
[4]Duff depth not measured postharvest.

Table 23.—Litter and duff depth and weight

	Fourth year postharvest[1]					Eighth year postharvest[2]	
	Litter & duff depth		Specific gravity	Kg/ha	Tons/acre	Duff and litter depth	
	cm	*Inches*	*g/cm*			*cm*	*Inches*
Undisturbed forest	2.6	1.02	0.13	35 494	15.83	0.9	0.35
Broadcast burn	1.8	.71	.17	34 995	15.61	not available	
Pile/burn							
Under piles	1.7	.67	.17	31 985	14.27	—	—
Between piles	1.3	.51	.23	33 222	14.82	1.2	.47
Residue-removed	2.4	.94	.20	42 213	18.83	2.2	.87
Chip-spread	11.7	4.61	.16	180 582	80.56	11.2	4.41

[1]Field data and compilations by N. DeByle, INT, Logan.
[2]Field measurements by R. Benson, INT, Missoula.

Table 24.—Understory vegetation, fifth year after harvest, by treatment and subunit

Undisturbed forest[1]		Treatment							
		Pile/burn		Broadcast burn		Residue-removed		Chip-spread	
Sample unit	kg/ha	Sub-unit	kg/ha	Sub-unit	kg/ha	Sub-unit	kg/ha	Sub-unit	kg/ha
1	397	2S	637	2S	244	4S	422	4E	190
2	397	2N	438	2N	439	4N	700	4W	98
3	244	3S	267	3S	373	1W	389	1W	70
4	82	3N	363	3N	311	1E	809	1E	72
Mean	280		427		342		580		107
(Lb/acre)	(249)		(380)		(305)		(517)		(95)

[1]Sample subunits. **Undisturbed:** 1, 2, 3, 4 in forest adjacent to respective units. **Treatment:** 2S = Unit 2 South; 3S = Unit 3 South, etc., in respective treatments.

Source: W. Schmidt 1980.

Table 25.—Concentrations of available nutrients in mineral soil in 1977

Depth and treatment	Available phosphorus	Extractable Potassium	Extractable Calcium	Extractable Magnesium	Available Boron	Available Zinc	Available Iron
	ppm	*Meq/100 g*			*ppm*		
0-5 cm:							
Forest	31.2	0.50	7.55	1.42	1.65	4.08	230
Broadcast burned	50.8	.58	9.95	1.98	1.58	7.12	206
Piled/burned, under	60.8	.68	14.60	2.05	1.62	12.25	302
Piled/burned, between	48.8	.50	7.18	1.62	1.05	4.45	219
Residue-removed	59.2	.58	8.80	1.82	1.82	3.88	241
Chip-spread	67.5	.55	8.22	1.72	1.78	4.08	446
5-15 cm:							
Forest	34.8	.42	4.68	0.98	0.85	1.55	256
Broadcast burned	49.2	.40	5.40	1.25	.65	2.20	266
Piled/burned, under	56.2	.60	6.78	1.62	1.50	4.95	305
Piled/burned, between	48.0	.40	5.72	1:25	1.22	7.32	280
Residue-removed	55.5	.45	6.02	1.35	.95	2.10	284
Chip-spread	62.2	.45	6.10	1.40	.90	2.60	445

Source: N. DeByle 1980.

Table 26.—Average concentrations of nutrients in soil solutions, 1977

Nutrient	Treatment: Forest	Broadcast burn	Pile/ burn (under)	Pile/ burn (between)	Residue-removed	Chip-spread
	mg/liter					
Nitrate-nitrogen	0.1	1.5	4.4	1.2	1.0	0.9
Potassium	.6	1.6	2.0	1.0	1.0	1.6
Calcium	2.6	5.3	11.9	4.2	4.2	6.8
Magnesium	.7	1.4	3.3	1.1	1.1	1.6
Sodium	1.4	1.1	2.2	1.0	2.0	1.2

Source: DeByle 1980.

Table 27.—Nutrients and ash in biomass per hectare of surviving 2-0 lodgepole pine, five growing seasons after planting

Treatment and tree component	N	P	K	Ca	Mg	Ash
	Grams/hectare					
Broadcast burned						
Needles	316	36	149	54	27	643
Wood, bark, buds	120	19	84	25	20	463
Roots	32	7	28	11	11	451
Total	**468**	**62**	**261**	**90**	**58**	**1 557**
Piled/burned						
Needles	388	38	147	88	30	850
Wood, bark, buds	170	28	113	32	28	644
Roots	39		9	33	101	1 476
Total	**597**	**75**	**293**	**130**	**69**	**1 970**
Residue-removed						
Needles	185	20	74	27	13	337
Wood, bark, buds	81	12	53	18	13	268
Roots	20	4	17	8	7	275
Total	**286**	**36**	**144**	**53**	**33**	**880**
Chip-spread						
Needles	83	10	35	11	6	152
Wood, bark, buds	36	6	24	6	5	105
Roots	13	3	9	4	4	141
Total	**132**	**19**	**68**	**21**	**15**	**398**

Source: DeByle 1980.

Table 28.—Volume and value of timber harvest, actual 1971 conditions (volumes per acre not adjusted)

	Conventional			Residue removed		
	Vol/acre[1]	$/unit	$/acre	Vol/acre[1]	$/unit	$/acre
Preharvest, ft^3/acre	10,175	—	—	9,675	—	—
Postharvest, ft^3/acre	3,567	—	—	729	—	—
Harvest costs						
Saw log, ft^3/acre	6,608			4,366		
M bd.ft./acre	23.2	[2]20.26	470	15.0	[2]20.64	310
Residues, ft^3/acre	0	0	0	4,580	[3].137	627
Total costs			470			937
Values						
Saw log, M bd.ft.	23.2	[4]55.71	1,292	15.0	[4]55.71	836
Chips, ft^3	0	0	0	4,580	[5].129	591
Net value of timber:						
with chips			822			480
without chips			822			– 101

[1]Gardner and Hann 1972.
[2]Stump to truck (hauling cost of $12.90/M bd.ft. deducted); from Gardner and Hartsog 1973.
[3]Chip costs converted from 2,400 lb Bone Dry Unit (BDU) at rate of 96 ft^3 solid wood per unit. Costs stump to chipper = $0.096/$ft^3$; through chipper = $0.137/$ft^3$. (Hauling costs deducted.) From Gardner and Hartsog 1973.
[4]1971 values on truck $55.71/M bd.ft., based on sales in area.
[5]Assumes chip values = $0; or $12.42/96 ft^3 BDU (1971 price at mill = $21, less $6.48 haul cost, less $2.10 screen loss).

Table 29.—Cost of postharvest activities

	Actual cost 1971	Adjusted to 1980 dollars[1]
	Dollars per acre	
Broadcast burn		
Fireline	4.86	8.70
Burn (including overhead)	13.81	24.72
Planting	122.89	219.98
Seeding	75.33	134.84
Pile/burn		
Piling	35.71	63.92
Burn (including overhead)	7.70	13.78
Planting	133.48	238.93
Seeding	61.12	109.40
Residue-removed		
Planting	156.92	280.87
Seeding	66.93	119.80
Chip-spread		
Planting	146.00	261.34
Seeding	53.05	94.96
All areas		
Fencing	61.50	110.08
Rodent control	3.00	5.37

[1]Using GNP implicit price deflator, 1972 = 100:

$$\frac{1980 = 172}{1971 = 96} = 1.79 \times 1971 \text{ dollars} = 1980 \text{ dollars.}$$

Table 30.—Volume and value of timber harvest under assumptions of equal (adjusted) volume per acre and improved saw log recovery

	Conventional			Residue-removed		
	Volume/acre	$/unit	$/acre	Volume/acre	$/unit	$/acre
Preharvest, ft³/acre[1]	9,800	—	—	9,800	—	—
Postharvest[1]	3,435	—	—	738	—	—
Harvest costs						
Saw logs	[2]20	20.26	405	[2]20	20.64	413
Residue	0	0	0	2,877	.137	394
Total cost						
1971 dollars			405			807
1980 dollars[3]			725			1,444
Values						
Saw log	[2]20	55.71	1,114	[2]20	55.71	1,114
Residue	0	0	0	2,877	.129	371
Total value						
1971 dollars			1,114			1,485
1980 dollars[3]	1,994	2,658				
Net timber values:						
1971 dollars			709			678
1980 dollars[3]			1,269			1,214

[1]Assumed volume for both treatments equals 9,800 ft³/acre; postharvest residue components derived by adjusting table 28 (actual volume) up or down proportionately.

[2]Assumes saw log recovery improved to 20 M bd.ft. on residue-removed, and chip recovery adjusted accordingly.

[3]Using GNP implicit price deflator (1972 = 100): 1971 = 96, 1980 = 172; and therefore 1980 dollars = $\frac{172}{96}$ = 1.79 X 1971 dollars.

Table 31.—Stocking, average size, and volume of green trees at culmination of board foot MAI (assumes no substantial mortality between ages 5 and 20)

Treatment[2]	Average tree at culmination of board foot MAI					Total[3] green residue
	No./ acre	Diameter	Height	Board foot	Top[3] (2-6 in)	
					Ft[3]	*Ft[3]/acre*
Pile/burn						
P	400	9.1	67	47	2.8	1,120
S	458	8.5	62	36	2.6	1,190
N	675	7.4	71	28	3.7	2,497
Broadcast burn						
P	400	9.1	67	47	2.7	1,080
S	400	9.1	67	47	2.7	1,080
N	198	12.1	77	117	2.0	396
Chip-spread						
P	225	11.6	77	104	2.1	472
S	176	12.4	74	119	1.8	317
N	157	13.1	77	146	1.8	283
Residue-removed						
P	249	11.2	76	94	2.2	548
S	400	9.1	67	47	2.8	1,120
N	532	8.1	67	34	3.5	1,862

[1]From table 14.
[2]See treatments, table 14.
[3]Developed from stand growth projections by D. M. Cole, INT, Bozeman.

Table 32.—Stocking, average size, and volume of green trees at culmination of board foot MAI (assumes 1.5 percent annual mortality between ages 5 and 20)

Treatment[2]	Average tree at culmination of board foot MAI					Total[3] green residue
	No./ acre	Diameter	Height	Board foot	Top[3] (2-6 in)	
					Ft[3]	*Ft[3]/acre*
Pile/burn						
P	297	10.4	72	73	2.2	653
S	208	11.9	77	112	2.0	416
N	614	7.7	71	31	3.5	2,149
Broadcast burn						
P	313	10.2	72	69	2.2	689
S	249	11.2	76	94	2.1	522
N	176	12.4	75	121	1.9	334
Chip-spread						
P	194	12.0	73	109	1.9	369
S	107	14.6	76	192	1.4	150
N	137	13.5	75	154	1.6	219
Residue-removed						
P	198	12.1	77	117	2.0	396
S	151	13.1	75	142	1.7	256
N	505	8.3	68	37	3.4	1,717

[1]From table 14.
[2]See treatments, table 14.
[3]Developed from stand growth projections by D. M. Cole, INT, Bozeman.

Table 33a.—Projected live and dead tree stocking and dead tree volume, by treatment[1] (assumes no substantial mortality between ages 5 and 20)

Treatment[2]	Live trees/acre: At "4.6"[3] d.b.h.	Live trees/acre: At 100 years	Live trees/acre: At bd.ft. MAI	Dead trees at 100 years: No.[4]/acre	Dead trees at 100 years: D.b.h.[5]	Dead trees at 100 years: Height[5]	Dead trees at 100 years: Volume[5]/tree	Additional at MAI: No.[4]/acre	Additional at MAI: D.b.h.[5]	Additional at MAI: Height[5]	Additional at MAI: Volume[6]/tree	Total dead at 100 years	Additional at MAI	Total at MAI
							Ft³				----	---- *Ft³*	----	----
PB/P	597	400	400	197	6	40	3.85	—	—	—	—	758	—	758
S	646	419	419	227	6	40	3.85	—	—	—	—	874	—	874
N	1,702	976	675	726	5	45	3.00	301	6	60	5.69	2,178	1,713	3,891
BB/P	597	400	400	197	7	45	5.80	—	—	—	—	1,143	—	1,143
S	597	400	400	197	7	45	5.80	—	—	—	—	1,143	—	1,143
N	299	228	198	71	8	50	8.30	30	10	65	16.43	589	493	1,082
CS/P	349	261	225	88	7	40	5.18	36	10	65	16.43	456	591	1,047
S	240	188	176	52	9	50	10.42	12	11	65	19.75	542	237	779
N	230	181	157	49	8	40	6.70	24	12	70	25.08	328	602	930
RR/P	399	291	249	108	7	45	5.80	42	9	60	12.42	626	522	1,148
S	597	400	400	197	7	45	5.80	—	—	—	—	1,143	—	1,143
N	1,001	588	532	413	5	35	2.38	56	7	60	7.65	983	428	1,411

[1]Developed from projections by D. M. Cole, INT, Bozeman.
[2]See treatment column, table 14.
[3]From projection: "4.6" is at a variable age.
[4]By subtraction using projection.
[5]Estimated from average size by decade.
[6]Computed from Faurot 1977.

Table 33b.—Projected live and dead tree stocking and dead tree volume, by treatment[1] (assumes no 1.5 percent annual mortality between ages 5 and 20)

	Live trees/acre			Dead trees at 100 years				Additional at MAI						
Treatment[2]	At "4.6"[3] d.b.h.	At 100 years	At bd.ft. MAI	No.[4]/ acre	D.b.h.[5]	Height[5]	Volume[5]/ tree	No.[4]/ acre	D.b.h.[5]	Height[5]	Volume[6]/ tree	Total dead at 100 years	Additional at MAI	Total at MAI
							*Ft*³				*Ft*³	*Ft*³	*Ft*³	*Ft*³
PB/P	430	322	297	208	7	40	5.18	25	10.0	70	17.65	1,077	441	1,518
S	319	241	208	78	8	40	6.70	33	11.0	70	21.21	523	700	1,223
N	1,437	870	614	567	5	45	3.00	256	7.0	65	8.24	1,701	2,109	3,810
BB/P	488	340	313	148	6	35	3.45	27	10.0	70	17.65	511	476	987
S	399	291	249	108	6	35	3.45	42	10.0	70	17.65	373	741	1,114
N	240	188	176	52	7	35	4.54	12	12.0	70	25.08	241	301	542
CS/P	270	208	194	62	8	40	6.70	14	11.5	70	22.95	415	321	736
S	140	114	107	26	8	35	5.90	7	14.0	70	33.75	153	236	489
N	180	146	137	34	8	35	5.90	8	13.0	70	29.26	184	234	418
RR/P	299	228	198	71	7	35	4.54	30	11.0	75	22.45	322	673	995
S	200	161	151	39	8	40	6.70	10	12.0	75	26.85	261	268	529
N	919	557	505	362	6	40	3.85	52	8.0	65	10.70	3,873	525	4,398

[1]Developed from projections by D. M. Cole, INT, Bozeman.
[2]See treatment column, table 14.
[3]From projection: "4.6" is at a variable age.
[4]By subtraction using projection.
[5]Estimated from average size by decade.
[6]Computed from Faurot 1977.

Table 34.—Summary of saw log and residue volume at culmination of mean annual board foot increment

Treatment[1]	Saw log	Residues Green	Residues Dead	Residues Total
	M bd.ft./acre	*Ft³/acre*		
Assumes no mortality between ages 5 and 20				
PB/P	18.7	1,120	758	1,878
S	16.6	1,190	874	2,064
N	19.0	2,497	3,891	6,388
BB/P	18.7	1,080	1,143	2,223
S	18.7	1,080	1,143	2,223
N	23.1	396	1,082	1,478
CS/P	23.3	472	1,047	1,519
S	21.0	317	779	1,096
N	22.9	283	930	1,213
RR/P	23.4	548	1,148	1,696
S	18.7	1,120	1,143	2,263
N	18.1	1,862	1,411	3,273
Assumes 1.5 percent annual mortality, ages 5 to 20				
PB/P	21.6	653	1,518	2,171
S	23.2	416	1,223	1,639
N	19.3	2,149	3,810	5,959
BB/P	21.6	689	987	1,676
S	23.4	522	1,114	1,636
N	21.3	334	542	876
CS/P	21.1	369	736	1,105
S	20.5	150	489	639
N	21.1	219	418	637
RR/P	23.1	396	995	1,391
S	21.4	256	529	785
N	18.7	1,717	4,398	6,115

[1]See treatments, table 14.

Table 35a.—Summary of expected timber values, based on projected volumes, and 1971 logging costs and values (in 1980 dollars) (assumes no substantial mortality between ages 5 and 20)

1971 treatment[1]	Projected future stand: Saw log only — Volume	Harvest cost[2]	Value[2]	Net	Residues (chipped) — Volume	Harvest cost[2]	Value[3]	Net	Total net (saw log and chips)
	M bd.ft./acre	*$/acre*			*Ft³/acre*	*$/acre*			*$/acre*
PB/P	18.7	678	1,865	1,187	1,878	460	434	−26	1,161
S	16.6	602	1,655	1,053	2,064	506	477	−29	1,004
N	19.0	689	1,894	1,205	6,388	1,565	1,476	−89	1,116
BB/P	18.7	678	1,865	1,187	2,223	545	513	−32	1,155
S	18.7	678	1,865	1,187	2,223	545	513	−32	1,155
N	23.1	838	2,303	1,465	1,478	362	341	−21	1,444
CS/P	23.3	861	2,323	1,462	1,519	372	350	−22	1,440
S	21.0	776	2,094	1,318	1,096	268	253	−15	1,081
N	22.9	846	2,283	1,437	1,213	297	280	−17	1,196
RR/P	23.4	865	2,333	1,468	1,696	415	392	−23	1,445
S	18.7	691	1,865	1,174	2,263	554	523	−31	1,143
N	18.1	669	1,805	1,136	3,273	802	756	−46	1,090

[1]See treatments, table 14.
[2]At 1980 cost of $36.27/M bd.ft. in PB & BB; $36.95/M bd.ft. in CS & RR; $0.245/ft³ residues in all units.
[3]At 1980 values = 1.79 X 1971 values = $99.72/M bd.ft. saw logs and $0.231/ft³ for chips.

Table 35b.—Summary of expected timber values, based on projected volumes, and 1971 logging costs and values (in 1980 dollars) (assumes 1.5 percent annual mortality between ages 5 and 20)

1971 treatment[1]	Projected future stand: Saw log only — Volume	Harvest cost[2]	Value[2]	Net	Residues (chipped) — Volume	Harvest cost[2]	Value[3]	Net	Total net (saw log and chips)
	M bd.ft./acre	*$/acre*			*Ft³/acre*	*$/acre*			*$/acre*
PB/P	21.6	783	2,153	1,371	2,171	532	501	−31	1,340
S	23.2	841	2,313	1,472	1,639	401	379	−22	1,450
N	19.3	700	1,924	1,225	5,959	1,460	1,376	−83	1,142
BB/P	21.6	783	2,154	1,371	1,676	410	387	−23	1,348
S	23.4	849	2,333	1,484	1,636	401	378	−23	1,461
N	21.3	772	2,124	1,352	876	215	202	−13	1,339
CS/P	21.1	780	2,104	1,324	1,105	271	255	−16	1,308
S	20.5	757	2,044	1,287	639	156	148	−8	1,279
N	21.1	780	2,104	1,324	637	156	148	−8	1,316
RR/P	23.1	853	2,303	1,450	1,291	341	321	−20	1,430
S	21.4	791	2,134	1,343	785	192	181	−11	1,332
N	18.7	691	1,865	1,174	6,115	1,498	1,412	−86	1,088

[1]See treatments, table 14.
[2]At 1980 cost of $36.27/M bd.ft. in PB & BB; $36.95/M bd.ft. in CS & RR; $0.245/ft³ residues in all units.
[3]At 1980 values = 1.79 X 1971 values = $99.72/M bd.ft. saw logs and $0.231/ft³ for chips.

Table 36.—Worksheet for deriving grazing values, by treatment

A. WEIGHT OF UNDERSTORY VEGETATION AVAILABLE[1] AND UTILIZABLE[2] ANNUALLY

Treatment	Period (years after harvest) 1-10 Production	1-10 Utilization	11-25 Production	11-25 Utilization	26-100 Production	26-100 Utilization
	Lb/acre					
Uncut	300	150	300	150	300	150
Residue-removed	None—No grazing allowed		650	325	300	150
Chip-spread	None—No grazing allowed		75	37	300	150
Pile/burn	None—No grazing allowed		700	350	300	150
Broadcast burn	None—No grazing allowed		800	400	300	150

B. AVERAGE ANNUAL WEIGHT OF UTILIZABLE VEGETATION OVER 100-YEAR PERIOD

Treatment	[1st 10 years X]	+ [15 years X]	+ [75 years X] [÷ 100 years]	= [average annual for 100-yr period]
Uncut	150	150	150	150
Residue-removed	0	325	150	161
Chip-spread	0	37	150	113
Pile/burn	0	350	150	165
Broadcast burn	0	400	150	172

C. AUM's[3] AND AVERAGE ANNUAL VALUE[4] FOR GRAZING, FOR PERIODS 11-25 YEARS, AND FOR 100 YEARS

Treatment	Grazing period 11-25 years only AUM/acre/yr	Grazing period 11-25 years only Value/yr	Grazing for 100 years AUM/acre/yr	Grazing for 100 years Value/yr
Uncut	0.19	0.42	0.19	0.42
Residue-removed	.42	.94	.21	.47
Chip-spread	.05	.11	.14	.31
Pile/burn	.45	1.01	.21	.47
Broadcast burn	.51	1.15	.22	.49

[1]Derived from Basile projection, figure 20.
[2]Assumed: 50 percent of vegetation is available.
[3]Assumed: 2.6 pounds forage/cwt, for a 1,000-lb cow (AUM) = 26 lb/day, X 30 days = 780 lb/AUM.
[4]Assumed: $2.25/AUM (this is slightly higher than central-Montana and Wyoming fees for 1979).

Table 37.—Wildlife evaluation for various species, alternative harvest systems, lodgepole pine type, Teton National Forest
(Index: 0 = least favorable for species; 100 = most favorable for species)

		Year 1		Year 20		Year 100	
		Forage	Cover	Forage	Cover	Forage	Cover
Moose							
Uncut stand		90	100	80	100	70	100
Residue-removed	Natural regeneration	10	0	50	50	90	100
	Planted	10	0	50	70	90	100
Chip-spread	Natural regeneration	0	0	10	10	30	40
	Planted	0	0	10	50	30	100
Pile/burn	Natural regeneration	5	5	50	50	90	100
	Planted	5	5	50	70	90	100
Broadcast burn	Natural regeneration	5	5	50	50	90	100
	Planted	5	5	50	70	90	100
Elk							
Uncut stand		70	100	60	100	50	100
Residue-removed	Natural regeneration	10	0	100	50	90	100
	Planted	0	0	100	70	90	100
Chip-spread	Natural regeneration	0	0	10	10	40	50
	Planted	0	0	10	50	40	100
Pile/burn	Natural regeneration	5	0	100	50	90	100
	Planted	5	0	100	70	90	100
Broadcast burn	Natural regeneration	5	0	100	50	90	100
	Planted	5	0	100	70	90	100
Birds							
Residue-removed	Natural regeneration	10	0	50	70	90	100
	Planted	10	0	50	80	80	90
Chip-spread	Natural regeneration	0	0	10	40	30	50
	Planted	0	0	10	50	30	90
Pile/burn	Natural regeneration	10	30	80	70	90	100
	Planted	10	30	80	80	90	90
Broadcast burn	Natural regeneration	10	30	80	70	90	100
	Planted	10	30	90	80	90	90
Pocket gophers							
Uncut stand		30		30		40	
Residue-removed	Natural regeneration	10		100		60	
	Planted	10		80		50	
Chip-spread	Natural regeneration	0		10		20	
	Planted	0		5		10	
Pile/burn	Natural regeneration	10		100		60	
	Planted	10		80		50	
Broadcast burn	Natural regeneration	10		100		60	
	Planted	10		80		50	

Source: G. Gruell, Office Report, Teton National Forest, June 15, 1973.

Table 38.—Managers' esthetic evaluation for alternative harvest method first year after logging and projections for 10 and 20 years hence
(Index number: 0 = low esthetic value; 100 = high esthetic value)

Activity viewpoint	Uncut stand	Pile/burn	Residue-removed	Chip-spread
First year				
Moving car	100	20	73	67
Hiking or horseback	100	10	71	65
Camping	100	15	73	67
Picture taking	100	10	71	65
From overlook	100	5	68	62
From aircraft	100	20	73	67
Recreation day use	100	5	71	65
Year 10				
Moving car	94	30	88	69
Hiking or horseback	88	20	83	67
Camping	90	25	88	69
Picture taking	85	20	83	67
From overlook	80	15	78	64
From aircraft	95	30	88	69
Recreation day use	80	15	78	67
Year 20				
Moving car	77	45	100	71
Hiking or horseback	70	35	100	69
Camping	72	40	100	71
Picture taking	70	35	100	69
From overlook	68	30	100	66
From aircraft	77	45	100	71
Recreation day use	68	30	100	69

Source: Derived from office report, "Wyoming Logging Residue Study—Esthetic and Recreation Evaluation," by Reed Stalder, USDA Forest Service, R-4, Ogden, Utah.

Benson, Robert E. Management consequences of alternative harvesting and residue treatment practices—lodgepole pine. Gen. Tech. Rep. INT-132. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 58 p.

Logging residues in lodgepole pine were treated by four methods: broadcast burned, piled and burned, removed from site, and chipped and spread on site. Each treatment was regenerated by planted seedlings, direct seeding, and natural regeneration. Effects on soil, water, microsite, microorganisms, vegetative development, wildlife habitat, and visual qualities were observed during a 10-year period. Analyses were made of immediate and projected long-term costs and benefits for both dollar and nondollar resource values.

KEYWORDS: lodgepole pine, slash disposal, logging costs, utilization, regeneration, soil and water, microsite, visual quality, value index

The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)